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EXAMINATION AND PREDICTION OF PROBLEMS ASSOCIATED WITH COLLOCATING ATC-VHF COMMUNICATION SYSTEMS

W. J. Hartman
and
J. J. Tary

December 1975

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16. Abstract

Problems associated with collocating air traffic control-VHF communications systems are investigated for the purpose of comparing predicted results with measurements, and comparing laboratory measurements with measurements taken at operating sites. It is reaffirmed that the characteristics of specific equipments are one of the most important variables, and these characteristics can be adequately measured in the laboratory for predicting their effects in an operational environment.

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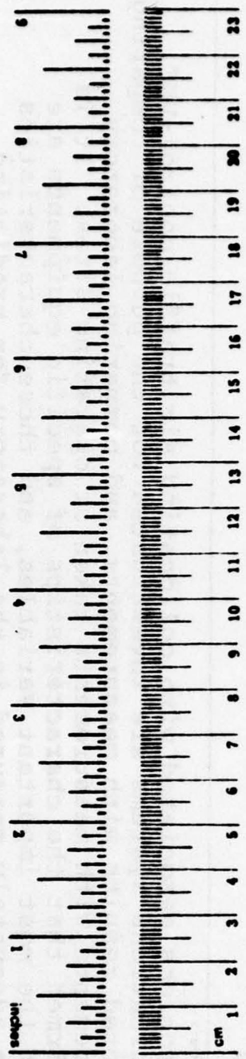
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

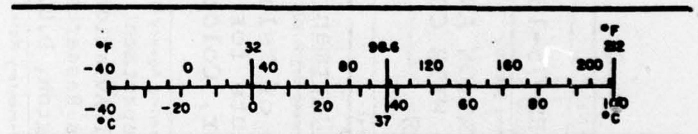
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



FEDERAL AVIATION ADMINISTRATION
SYSTEMS RESEARCH AND DEVELOPMENT SERVICE
SPECTRUM MANAGEMENT STAFF

STATEMENT OF MISSION

The mission of the Spectrum Management Staff is to assist the Department of State, Office of Telecommunications Policy, and the Federal Communications Commission in assuring the FAA's and the nation's aviation interests with sufficient protected electromagnetic telecommunications resources throughout the world to provide for the safe conduct of aeronautical flight by fostering effective and efficient use of a natural resource - the electromagnetic radio frequency spectrum.

This objective is achieved through the following services:

- Planning and defending the acquisition and retention of sufficient radio frequency spectrum to support the aeronautical interests of the nation, at home and abroad, and spectrum standardization for the world's aviation community.

- Providing research, analysis, engineering, and evaluation in the development of spectrum related policy, planning, standards, criteria, measurement equipment, and measurement techniques.

- Conducting electromagnetic compatibility analyses to determine intra/inter-system viability and design parameters, to assure certification of adequate spectrum to support system operational use and projected growth patterns, to defend aeronautical services spectrum from encroachment by others, and to provide for the efficient use of the aeronautical spectrum.

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- Providing spectrum management consultation, assistance, and guidance to all aviation interests, users, and providers of equipment and services, both national and international.

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EXAMINATION AND PREDICTION OF PROBLEMS ASSOCIATED WITH COLLOCATING ATC-VHF COMMUNICATION SYSTEMS

W. J. Hartman and J. J. Tary*

Problems associated with collocating air traffic control-VHF communications systems are investigated for the purpose of comparing predicted results with measurements, and comparing laboratory measurements with measurements taken at operating sites. It is reaffirmed that the characteristics of specific equipments are one of the most important variables, and these characteristics can be adequately measured in the laboratory for predicting their effects in an operational environment.

Key words: Air traffic control communications; Collocation of VHF systems.

1. INTRODUCTION

The problem of having collocated transmitting and receiving facilities is treated here in the setting of the Air Traffic Control (ATC) communications system which utilizes the VHF band from 118 to 136 MHz. Frequently, additional frequencies in the UHF band from 225 to 400 MHz are utilized in the same area and the interfering effects of these are also included.

Specifically, the problem is formulated in the following form: Given a particular site at which 3 VHF and 3 UHF voice communications channels are operating without mutual interference, under what conditions can one additional VHF

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receiving system be operated without harmful interference at the same site? If intermodulation products generated by more than three frequencies are insignificant, which is most often the case, the general cositing problem can be solved within this formulation by considering the various combinations of three VHF and three UHF frequency assignments.

The solution to the problem involves both theoretical predictions and laboratory measurements. The measurements are necessary to determine the particular equipment characteristics which cannot be satisfactorily predicted at this time.

Measurements taken at a remote communication air-ground (RCAG) site are compared with the predicted values, and also with the prediction obtained from the Cosite Analysis Model program (COSAM) developed at the Electromagnetic Compatibility Analysis Center (ECAC) (Hughes and Lustgarten, 1973; Shields and Radice, 1973).

2. GENERAL

2.1 Determining the frequencies at which interference might occur

A. Calculate those frequencies where emissions might occur. These include

1. Primary frequencies
2. Intermodulation products
3. Spurious emissions.

Construct a chart, as in figure 1, which is an example for the Aurora East RCAG site, showing third-order intermodulation products denoted by T and fifth-order products denoted by V. The three primary VHF frequencies also are shown by the dark squares covering ± 100 kHz on either side of the center frequency. This figure is a composite of the output of the program given in Appendix A.

Locate, from the measurements of the transmitter characteristics (see sec. 8), any spurious emissions and plot them.

B. Choose a new frequency to be used at the site which does not coincide with one of the possible interfering frequencies calculated in A. Use this frequency with all combinations of the original frequency assignments to calculate possible IM products in order to determine if these can cause interference with the original frequencies.

Determine the spurious responses of the receiver tuned to this frequency.

If the chosen frequency, or any of the spurious responses, falls on one of the emissions designated on the chart, the signal levels present and rejection levels must be calculated. If not, the frequency can be used.

NOTE OF CAUTION: Even though a spurious response does not appear in an adjacent channel, the presence of spurious responses nearby can increase the noise level by as much as 7 dB (see sec. 3).

2.2 Calculating power available at the receiver

The basic transmission loss between isotropic antennas is given by

$$L_B = -37.87 + 20 \log (f\ r), \text{ in decibels (dB)} \quad (1)$$

where f is the frequency in megahertz, and r is the distance between the transmitting and receiving antennas in feet (1 ft = 0.35 m). In the band from 118 to 136 MHz, this loss can be approximated to within 0.6 dB by

$$L_B = 4.2 + 20 \log (r). \quad (2)$$

The transmission loss is given by

$$L = 4.2 - G_T(f) - G_R(f) + L_f(f) + 20 \log r \quad (3)$$

where $G_T(f)$ and $G_R(f)$ are the antenna gains in the appropriate direction (possibly frequency dependent), and $L_f(f)$ is the loss (gain) associated with the waveguides or cables and any filters installed in the lines.

The power available at the receiver is given by $P_a(f)$ (dBm) = $P_T(f)$ - L, where $P_T(f)$ is the transmitter power (in dBm), and L is calculated for the path between the transmitter and receiver.

The transmitter intermodulation power is calculated from the expression (Shields and Radice, 1973):

$$P_{im} = mP_v + n(P_i - \beta_{vi}) - K_{m,n} - \beta_{vr} \tag{4}$$

where P_{im} is the power level (in dBm) of the intermodulation (IM) product at the transmitter at frequency f_{im}; P_v is the output power level (in dBm) of the victim transmitter signal at f_v; P_i is the received power level (in dBm) of the interfering transmitter signal at f_i; β_{vi} is the off-frequency rejection (in dB), a function of frequency difference between f_v and f_i and the victim transmitter output selectivity; $K_{m,n}$ is the transmitter conversion loss term for the m+n order case; and β_{vr} is the off-frequency rejection (in dB), a function of the difference between f_v and f_r where $f_r \simeq f_{im}$ and f_r is the tuned frequency of a victim receiver and $f_{im} = mf_v - nf_i$. Values for K_{21}, K_{32} and K_{43} have been computed from spectrum signatures (Hughes and Lustgarten, 1973; Shields and Radice, 1973).

2.3 Receiver response

The receiver intermodulation (IM) levels are given by $\ell P_a(f_1) + mP_a(f_2) + nP_a(f_3) + \gamma$ where the received frequency is expressed as $\pm \ell f_1 \pm mf_2, \pm nf_3$, and γ is the intermodulation value measured with a 0 dBm input level for all of the the frequencies f_1, f_2, and f_3.

For some higher level input powers, this will overestimate the intermodulation effect.

If the intermodulation measurements are not available, the following formulas can be used (Shields and Radice, 1973):

$P_{im} = m(P_v - \beta_{vr}) + n(P_i - \beta_{ir}) - K_{m,n}$ where P_{im} is the power (in dBm) of the intermodulation product produced in the receiver; P_v, and P_i are the power levels (in dBm) at the input to the receiver of the undesired signals; β_{vr}, β_{ir} is the off-frequency rejection (in dB), a function of the difference between undesired frequencies and receiver tuned frequency (f_r), where $f_r \approx f_{im}$; $f_r = mf_v - nf_i$; and $K_{m,n}$ is the receiver rf amplifier or first mixer conversion loss. Values of K_{11}, K_{21}, K_{32}, and K_{43} for the first mixer and K'_{11}, K'_{21}, K'_{32}, and K'_{43} for the rf amplifier have been computed from spectrum signature data.

The spurious response levels at the frequency f are calculated using

$$P_S(f) = 1.5\, P_a(f) + \Gamma(f), \tag{5}$$

where $\Gamma(f)$ is the response to 0 dBm input power.

It is recommended that the COSAM program (Hughes and Lustgarten, 1973) be used whenever the cositing problem involves large numbers of frequencies, requires computing transmitter intermodulation levels, or does not have the necessary measured characteristics for the receiver IM or spurious response.

2.4 Use of filters and cavities

Filters installed at the input to the receiver can be used to decrease the spurious response and receiver intermodulation (see sec. 4 for a description of the filter and cavity). The laboratory tests indicate that, with the use of the McCoy filter, adjacent channels can be separated by as little as 250 kHz (10 channels) as long as the undesired signal at the receiver is less than +5 dBm. The filter does raise the noise level to approximately -100 dBm out to several megahertz when adjacent channel signals are present. The cavity does not have the

selectivity of the filter, and spurious responses, when present, were still in evidence out to approximately ±500 kHz with the cavity installed.

Filters or cavities are useful when installed at the output of the transmitters for controlling spurious emissions and transmitter intermodulation.

2.5 Criteria for rejection of a frequency assignment

The following, listed in decreasing order of importance, are given by air traffic controllers as reasons for finding interference intolerable; (a) The undesired signal is demodulated and appears in the desired channel as an intelligible voice message, (b) The undesired signal distorts the desired signal, (c) The undesired signal breaks squelch and (d) The undesired signal increases the background noise level.

One additional condition was observed during the laboratory tests: the presence of an undesired signal too weak to break squelch, but sufficient to keep the squelch open after the desired signal was removed.

Each of these criteria was investigated and related to engineering measurements. The following guidelines can be used to determine the cause of the type of interference and the bounding signal levels.

Type (d) occurs when the undesired signal is several channels removed from the desired channel, the receiver has spurious responses of the type measured for the GRR-23 (i.e., very narrow-band responses), and the undesired signal level measured at the receiver AGC is approximately -100 dBm.

Type (c) occurs whenever the undesired signal exceeds -97 dBm into the receiver for a squelch level of 2 μV.

Because of frequency instabilities this may occur intermittently at frequencies where the receiver has spurious responses and at intermodulation frequencies, and thus should be considered in terms of frequency of occurence rather than an absolute level.

Type (b) occurs at either spurious response frequencies, or intermodulation frequencies when these occur slightly offset from the desired frequency. A variable signal level at the receiver AGC is a characteristic of this type of interference, with the highest level about -90 dBm.

Type (a) can occur whenever the signal is greater than -92 dBm.

3. GRR-23 RECEIVER MEASUREMENTS

The GRR-23 receiver normally uses a crystal controlled local oscillator (LO). However, since tuning was required during the measurement period, a signal generator was used to provide the LO frequency. Consequently, frequent calibration runs were necessary to insure that the difference between using the crystal and the signal generator was not significant. Typical calibrations, both with and without an undesired (off channel) signal present, are shown in figures 2 and 3.

Figure 4 shows the response of the GRR-23 as a function of frequency, showing the only differences observed using the crystal and the signal generator. The input level was +7 dBm. Figure 5 shows the same curve with the input level 0 dBm. Figure 6 shows the relationship between the input power level and the spurious response.

During the period of measurements, particularly when making the measurements using SCIM (see later this section), variations in the spurious response were noted. This led to the equipment configuration shown in figure 7, where the spectrum analyzer at IF could be used to find the spurious responses. These were only a few kilohertz wide and could easily be missed when scanning through the frequencies with the signal generator and observing only the AGC output. The results of these measurements are shown in figures 8a to 8o as the tuned frequency of the receiver is stepped by ten channels. For those channels where no spurious responses appeared, no figures are shown. No explanation for these spurious responses has been found. The effects appear to be variable as noted in section 2.

Figure 9 shows how the McCoy filter eliminates the spurs, but raises the noise level of the receivers.

Figure 10 shows some low level noise that appears when a signal at +7 dBm occurs at 123.1 MHz, approximately 700 kHz removed from the desired frequency. This phenomenon also occurred near other center frequencies.

Figure 11 shows the additional spurs that appear when the receiver LO frequency is changed, but the receiver is not fine adjusted at that frequency. The receiver in this example is fine tuned at 123.1 MHz and the spurs are indicated for the LO tuned to give desired frequencies of 123.6 or 122.6 MHz.

Figures 12 and 13 show the effects of tuning one signal generator with 0 dBm output while a second signal generator is on (figure 12) or off (figure 13) at a frequency 150 kHz removed from the tuned frequency of the receiver.

Figure 14 shows the measured receiver intermodulation for the GRR-23 and the King KY-195B. Signal generators tuned to 124.1 MHz and 125.95 MHz were used with a directional coupler to prevent transmitter intermodulation. With the McCoy filter installed, the intermodulation levels dropped approximately 25 dB.

The Speech Communication Index Meter (SCIM) is an automatic method for approximating articulation index scores. Measurements using SCIM (Gierhart et al., 1970) were made to indicate the voice performance of the channel. Figure 15 shows the SCIM scores as a function of input level to the GRR-23 from the GRT-21 transmitter with no interference present. As determined previously (Gierhart et al., 1970), a score of approximately 0.65 is acceptable for ATC voice communications over AM channels.

Figure 16 shows the SCIM scores for various values of desired to undesired signal ratios as a function of channel separation. The desired signal level was -68 dBm which produces a SCIM reading of 0.98 with no interference.

Figure 17 shows the desired to undesired ratio required to obtain different SCIM scores as a function of channel separation. The desired system for both figures 16 and 17 consists of the GRT-21 transmitter and the GRR-23 receiver, while the undesired signal curves are from the King 195B transmitter. The on-site experimental configuration, using the signal generator in place of the GRT-21 and the signal from the antenna as the undesired signal in place of the King, is shown in figure 18. The SCIM readings shown are for no signal present at the antenna. The coupler introduced a 17 dB loss.

Combined effects of different transmitters, modulation, and methods of measurements on cochannel response of the GRR-23 are shown for reference in figures 19 through 25.

4. McCOY FILTER AND SINCLAIR CAVITY

An active bandpass crystal filter (McCoy model 300A) was tested, and used in some of the experiments. The filter response is shown in figure 26. The filter reduced both the spurious responses and the receiver intermodulation of the GRR-23.

A tunable cavity (Sinclair L118-136) was also tested. The response is shown in figure 27. The cavity was not sufficiently selective to reduce the spurious receiver response, but did reduce the receiver intermod a small amount. The reduction in receiver intermod depends heavily on the frequencies involved because of the slowly decreasing skirts of the filter response.

5. BUEC* - RECEIVER MEASUREMENT

Two BUEC-TYFA 8191 VHF transceivers were tested. For many of the tests, the performance was the same, although, as noted later, some differences exist.

The AGC calibration for the BUEC receivers is highly nonlinear as shown in figures 28 and 29. The AGC values as a function of IF input power injected at the RF input (figure 30) and IF frequency (figure 31) show that at least 100 dB of attenuation is achieved at this frequency.

Response curves for 0, +4 and +7 dBm are shown for transceiver 214 in figure 32, and for 0 dBm input only for transceiver 224 in figure 33.

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*BUEC is an acronym for Backup Emergency Communications.

An unexplained phenomenon occurred on both BUEC transceivers. If the frequency of the BUEC receiver was stepped one channel at a time, the AGC reading dropped to 1.2 volts dc. However, if the channel was stepped by 1 MHz, the AGC rose to 2.6 volts dc, and then dropped gradually as the channels were stepped back by 25 kHz, as shown in figure 34. This phenomenon is not seen when the transmitter is varied. However, when the BUEC transmitter and receiver are used together, spurs, not noted when using the signal generator, appear as in figure 35.

Differences in the two receivers are noted in the (S+N)/N curves of figure 36, and in the comparison of the amount of rf power required to break squelch between the two receivers, as shown in figures 37 and 38.

The squelch setting on a receiver is used to suppress noise output when an rf carrier not greater than some predetermined level is present.

Figures 39 and 40 are plots of squelch behavior versus channels removed from the desired frequency of 120.0 MHz for the BUEC transceiver SN 214 and the BUEC transceiver SN 224. The settings of the squelch were identical for both receivers; namely, with the rf signal input level at -125 dBm, the squelch control was moved clockwise until the noise output just stopped. Beginning at approximately 8 channels above and below 120.0 MHz, the noise was not squelched when the rf signal was reduced. As seen from the figures, it would require a change of 10 to 25 dB for the receiver to recover and squelch the off channel signal.

The two receiver characteristics are very dissimilar in performance under like operating conditions.

The calibration of SCIM with varying input power is shown in figure 41 for the BUEC transceiver SN 214, and in figure 42 for the BUEC transceiver SN 224. Also shown in figure 42 is a calibration of SCIM for the DEI receiver which was used during part of the testing, primarily at frequencies outside the 118-136 MHz band.

The families of curves showing the desired to undesired signal ratios required to produce a given SCIM score are shown in figures 43 and 44.

At the fundamental and harmonic frequencies, the BUEC equipment also radiated power, as noted in figure 45. Power incident at the fuse holders also gave AGC readings through the BUEC receiver. This is shown for several frequencies in figure 46. This occurred at least up to L band, and was greatly reduced by covering the fuse holders with copper tape. The phenomenon completely disappeared when the BUEC transceiver was placed in a screen room, indicating the need for more adequate shielding on the BUEC equipment.

Figure 47 shows the output of the synthesizer at the fundamental and the harmonic frequencies.

6. KING AND DEI RECEIVERS

Two additional receivers were used during the tests, primarily for checking on other results. Although these receivers would not be used in an actual cosite environment, their characteristics are included here for comparison with the other equipment tested.

Figures 48 to 52 show measurements made on the King transceiver (KY-195B) and figure 53 shows the response of the DEI receiver.

7. MEASUREMENTS AT THE AURORA RCAG SITE

Several sets of measurements were made at a RCAG site, in Aurora, Colorado, using the signal incident on the unused VHF antenna as the undesired signal.

First, preliminary scans over all 720 channels (each 25 kHz) were made to determine at which frequencies signals were present. Second, SCIM measurements were made, using a desired signal level of -65 dBm at each predicted intermodulation frequency, and at ± 10 channels adjacent to the three primary channels at the site. Figure 54 shows the block diagram of the equipment configuration.

Figure 55 shows the SCIM readings at the intermodulation frequencies. The cochannel SCIM measurements are shown in figures 56 through 58. Compare these with figures 16 and 17. The on-site adjacent-channel SCIM performance measurements (figures 56, 57, and 58) were made in February at the FAA's RCAG East Site in Aurora, Colorado. Figure 56 shows SCIM readings above and below (in 25 kHz channel increments) the desired frequency of 128.65 MHz. These measurements were all made with the three VHF and three UHF transmitters keyed but not carrying any voice signals. Figure 57 is a repeat but centered at 125.95 MHz, and figure 58 is centered at 124.1 MHz. The worst signal performance appears when the frequency is centered at 125.95 MHz. Circuit A in figure 59 was tried first, but insufficient isolation was achieved, resulting in a signal of approximately -82 dBm at the antenna. Because it was suspected that this was reflection at the receiver, a 3 dB pad was inserted, resulting in the configuration in Circuit B in figure 59. This produced an additional 8 dB loss to the antenna, resulting in a radiated signal level of -90 dBm which was acceptable because of the separation from the other antennas in the system.

Prior to the SCIM measurements, several sets of signal level measurements were made at the site. One complete set of measurements was made using the GRR-23 receiver, with a signal generator as the LO source and with the receiver fine tuned every 20 channels (25 kHz wide). From the tuned frequency, the receiver was then stepped to ± 10 channels. In this fashion all 720 channels (25 kHz wide) were scanned, with all three UHF and

all 3 VHF frequencies at the site keyed during each channel measurement. The results of these measurements are shown in figure 60. The points marked "unknown" in this figure correspond either to frequencies assigned to the Aurora RCAG West Site located approximately 1000 yards (900 m) from the East Site, or to intermodulation products associated with these frequencies. However, it could not be confirmed that these frequencies were keyed at the time of the measurements.

Figure 61 shows the comparison of the predicted* and measured signal levels. The ITS predicted levels at the three primary frequencies are the same for the COSAM as those given by the formulas in section 2 of this report. The predictions of the receiver intermodulation given by the methods of section 2 using the receiver intermodulation lab measurements are shown in figure 61.for three of the third-order products. Since the transmitter intermodulation characteristics were not measured, no transmitter intermodulation predictions corresponding to the methods of section 2 are given here.

Laboratory and site measurements of third order intermodulation products using the King receiver are shown in figures 62 and 63. For the laboratory measurements shown in figure 62, the input level at each of the primary frequencies was -7dBm, while for the site measurements, the levels were -1 dBm at 128.65 MHz -4 dBm at 124.1 MHz, and +7dBm at 125.95 MHz. Using the on-site measured values of power at the primary frequencies, one would expect, from interpolating the laboratory measurements of intermodulation values, the on-site intermodulation products of -7 and -6 dBm at $2f_1-f_2$ and $2f_2-f_1$, respectively, which agrees with the site measurements.

One additional set of intermodulation measurements were made on site using the King receiver. These consisted of using Sinclair cavities in various combinations in the transmitter and receiver lines in order to distinguish between

*The predicted levels, labeled ECAC, were generously supplied by M. Lustgarten of ECAC.

transmitter and receiver intermodulation. These results are presented in table 1. It is clear that the intermodulation seen at 122.25 MHz and 127.8 MHz is primarily receiver intermodulation, while the intermodulation at 119.55 is primarily transmitter intermodulation.

Figure 64 shows those frequencies where possible interference might occur due to improper shielding of the receiver, as discussed previously in connection with the BUEC (section 5). Since the laboratory measurements showed only a very small leakage into the GRR-23, no signal was expected at these frequencies, and none was observed.

8. TRANSMITTER MEASUREMENTS

Several transmitters were available for brief periods of laboratory testing. A brief over-the-weekend frequency-drift test of the BUEC transceiver serial number 214 showed it to be well within specification. From the time plot, figure 65, a variation of approximately $\pm$ 11 Hz can be seen for the 46-hr period. This drift represents a tolerance of 0.00001% in the VHF air-to-ground band (118-136 MHz), which is better than the required specification for the equipment. The equipment configuration for this measurement is shown in figure 66.

The calibration of the spectrum analyzer for the measurement of the output of the transmitters is shown in figure 67. These calibrations apply to the spectral plots shown in figures 68 and 69. The spectrum analyzer was set to a bandwidth of 3 kHz with a scan of 100 kHz per division and a sweep time of 2 seconds per division. The input signal level was 0 dBm.

In order to emphasize the spurious emissions of the King transceiver, a notch filter was used to attenuate the carrier. These results are shown in figure 70. The analyzer is not calibrated for this figure.

Table 1. Measurements

Intermodulation Frequency Receiver: King KY-195B	3 VHF Transmitters Without Cavities Received Signal Level (dBm)	3 VHF Transmitters With Cavities Received Signal Level (dBm)
119.55 MHz		
Without Cavity	-78	-97
With Cavity	-84	-125
122.25 MHz		
Without Cavity	-35	-37
With Cavity	-62	-66
127.8 MHz		
Without Cavity	-13	-15
With Cavity	-50	-55

9. ACKNOWLEDGMENTS

The authors wish to acknowledge the support and assistance of the Federal Aviation Administration in this project effort. Special thanks are extended to Tom Annes, James I. Bruce, Charles H. Coburn, A. E. Hankinson, Daniel E. Lavato, Phil Liljestrand, and Richard G. Staats.

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Shields, J. P., and A. J. Radice (1973), Shaw AFB rivet switch collocation analysis, Department of Defense Electromagnetic Compatibility Analysis Center Report ESD-TR-73-030.

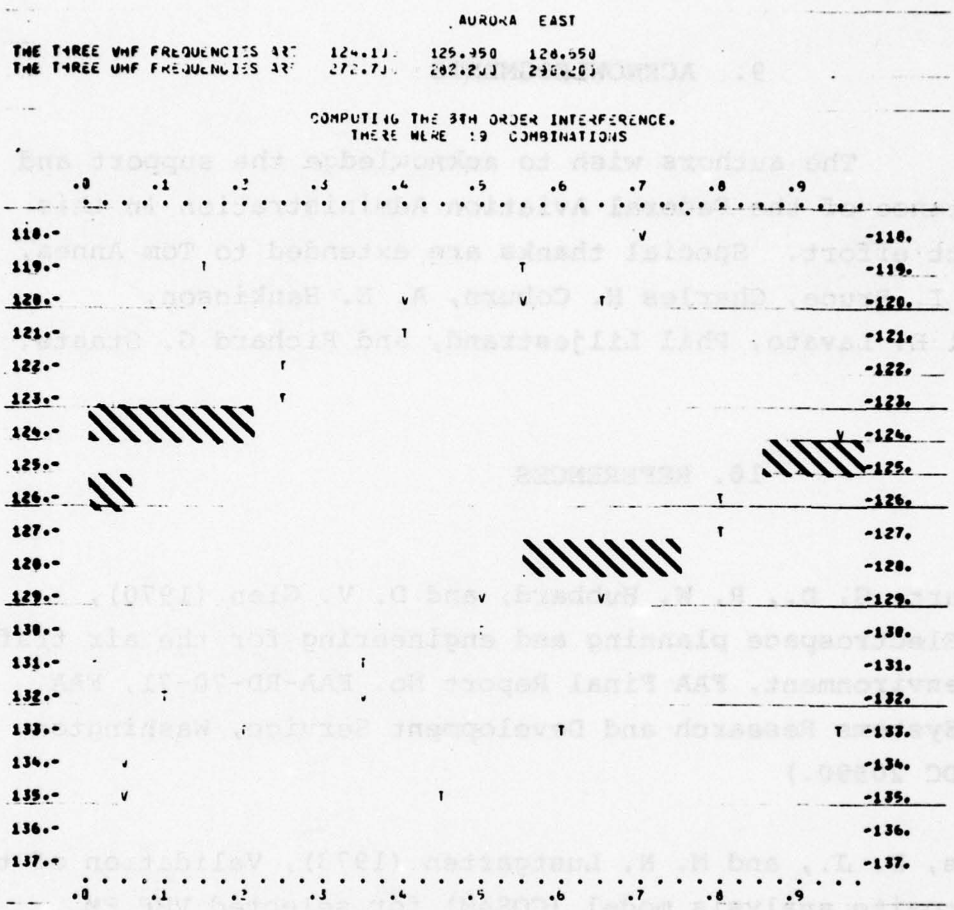


Figure 1. Chart of frequencies where possible interfering emissions can occur.

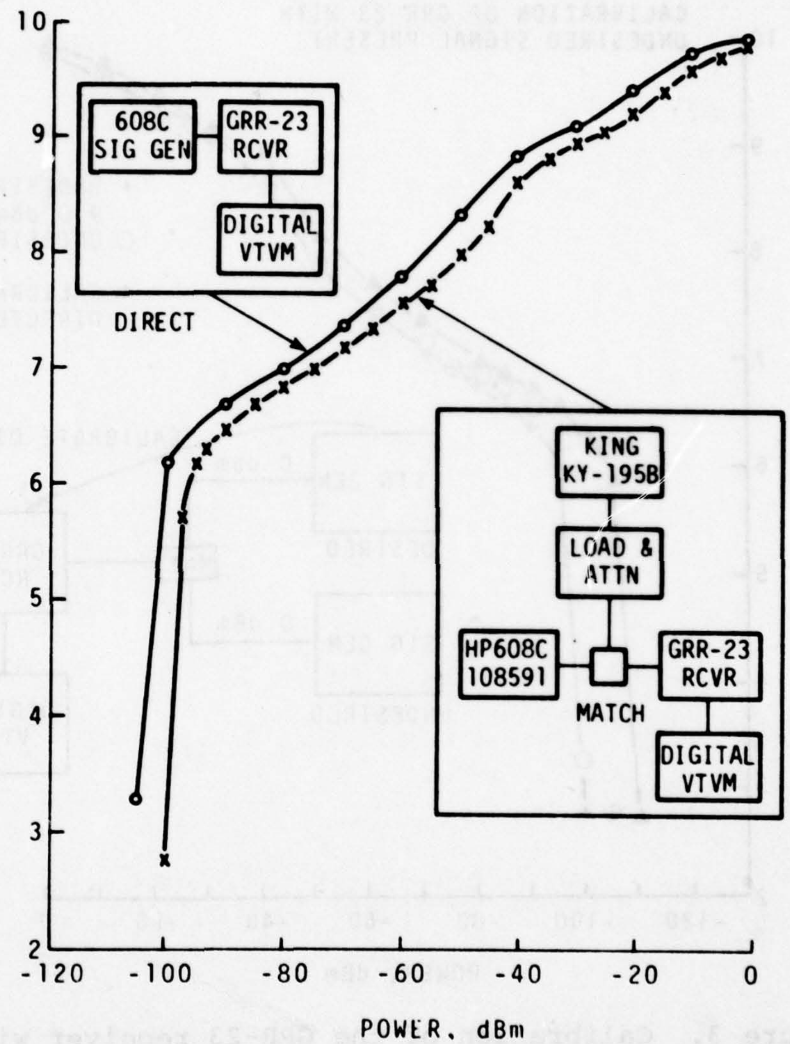


Figure 2. Calibration of the GRR-23 receiver (crystal controlled) at 123.1 MHz direct and through a matching network.

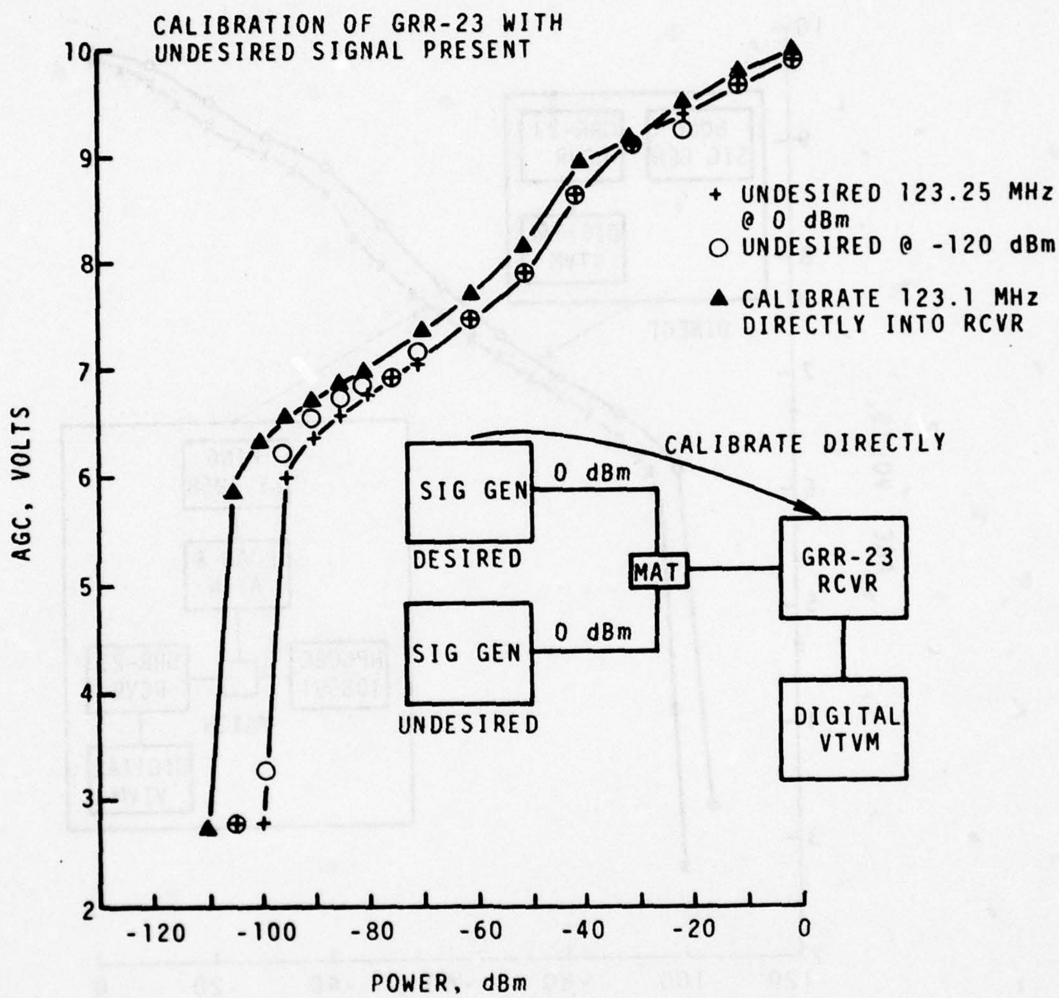


Figure 3. Calibration of the GRR-23 receiver with undesired signal present.

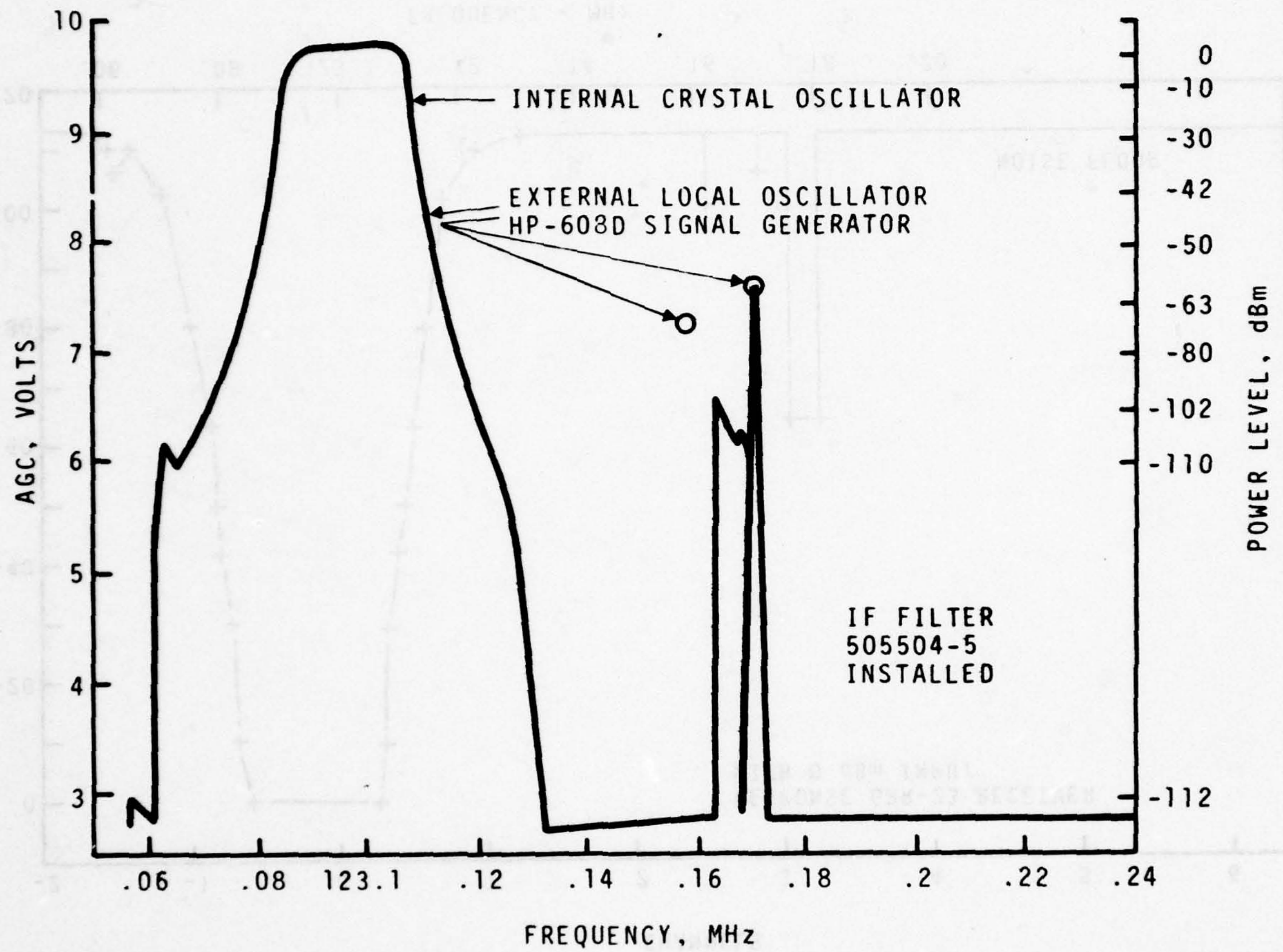


Figure 4. Spurious response for the GRR-23 crystal controlled receiver before and after subjection to + 7 dBm signal level.

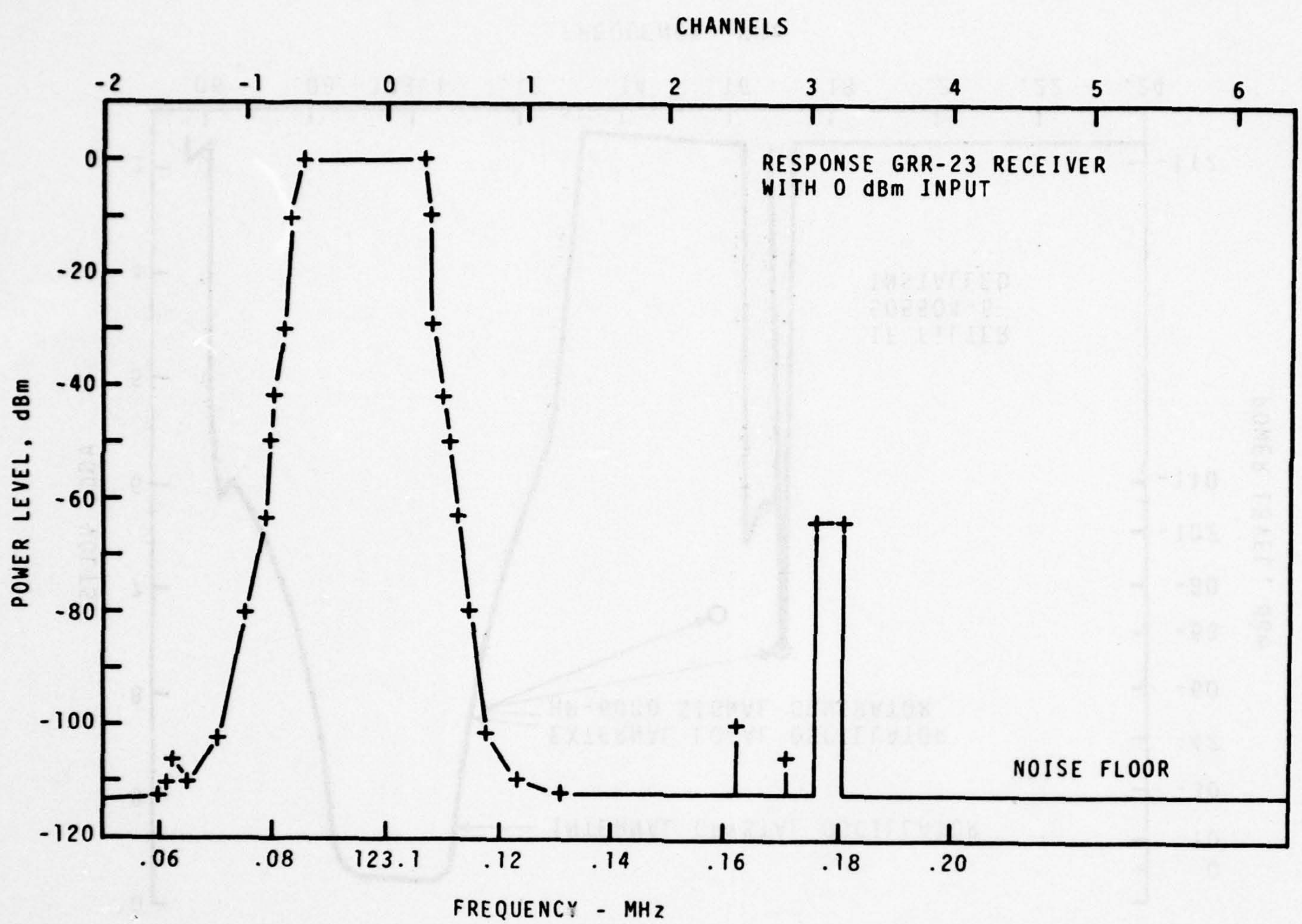


Figure 5. Response of GRR-23 receiver with 0 dBm input.

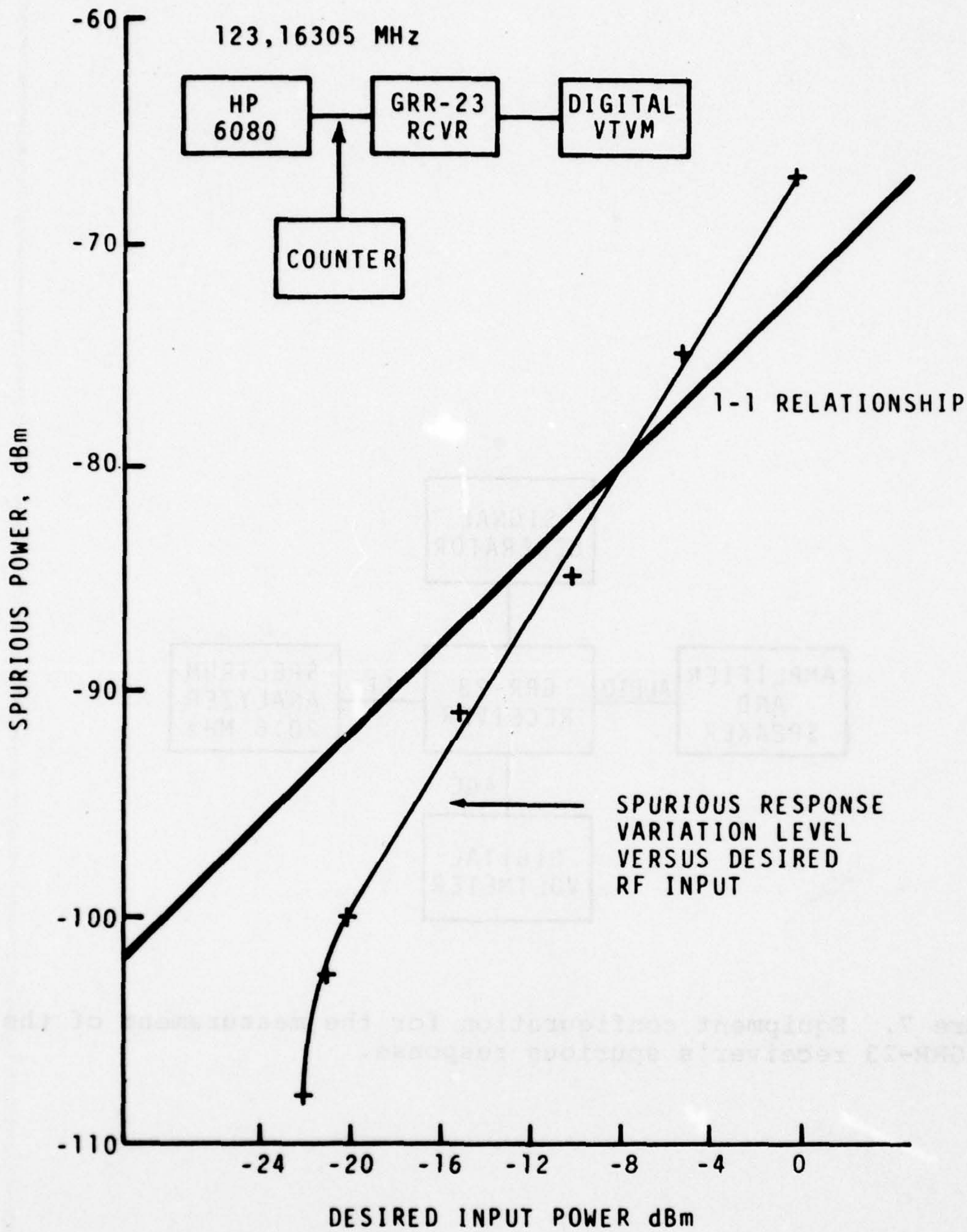


Figure 6. Spurious response variation level versus desired rf input. (GRR-23 receiver).

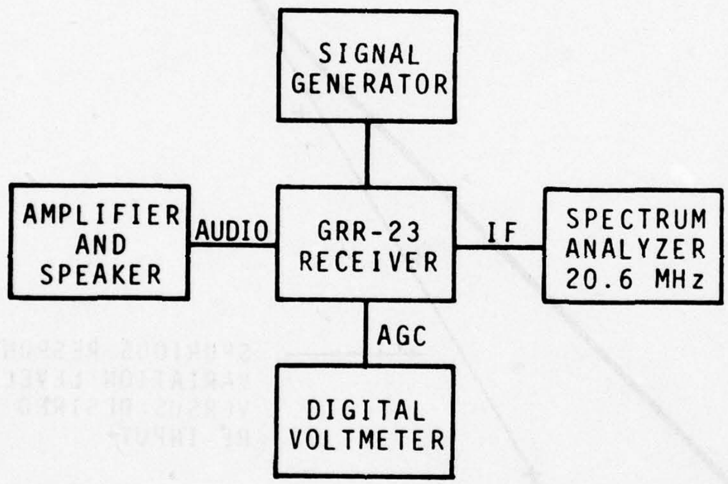


Figure 7. Equipment configuration for the measurement of the GRR-23 receiver's spurious response.

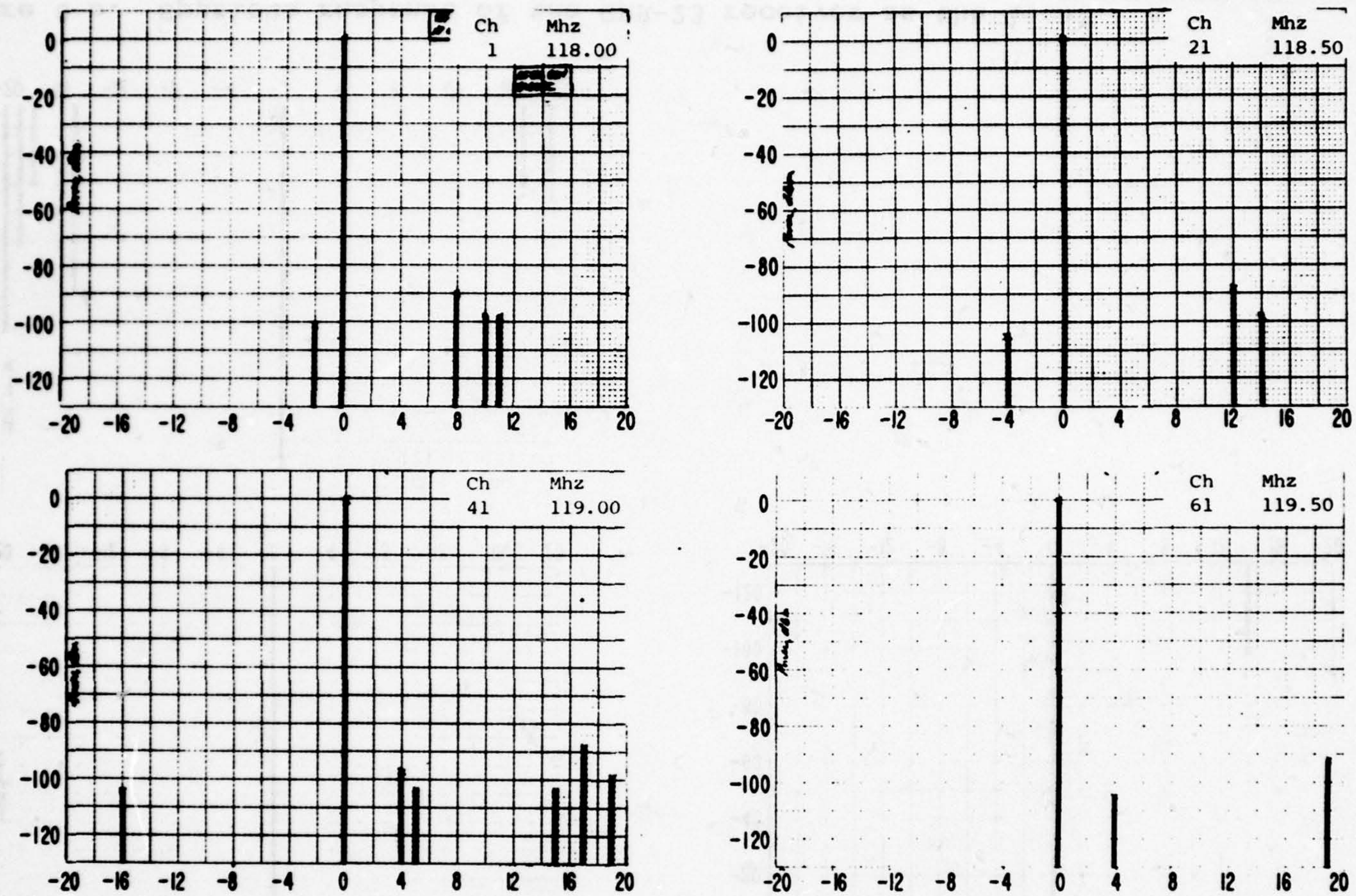


Figure 8 a. **Spurious response of the GRR-23 receiver as the local oscillator frequency was varied and the receiver retuned every 10 channels. The ordinate is channel spacing (25 kHz) and the abscissa is dBm.**

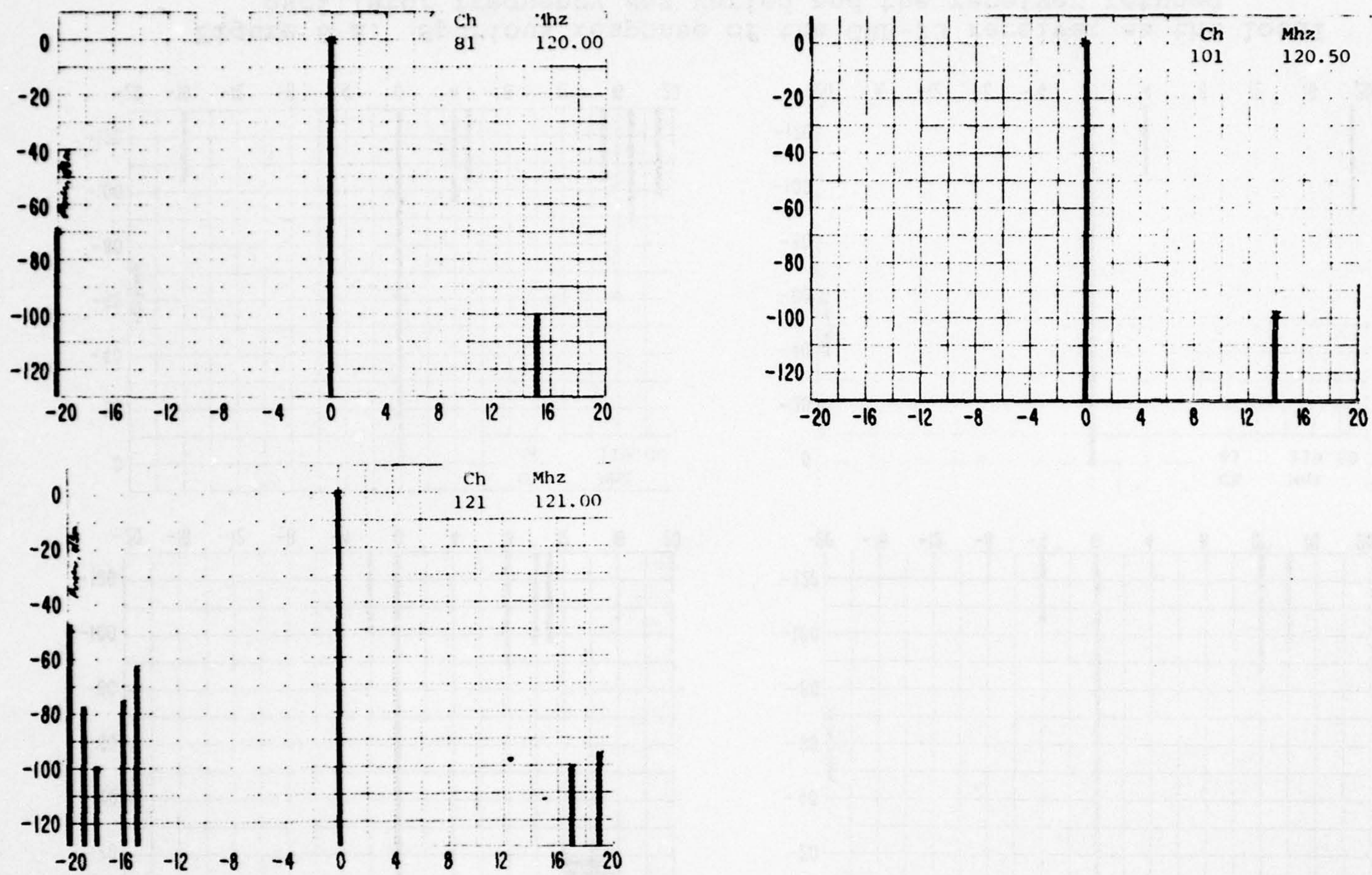


Figure 8 b. Spurious response of the GRR-23 receiver as the local oscillator frequency was varied and the receiver retuned every 10 channels. The ordinate is channel spacing (25 kHz) and the abscissa is dBm.

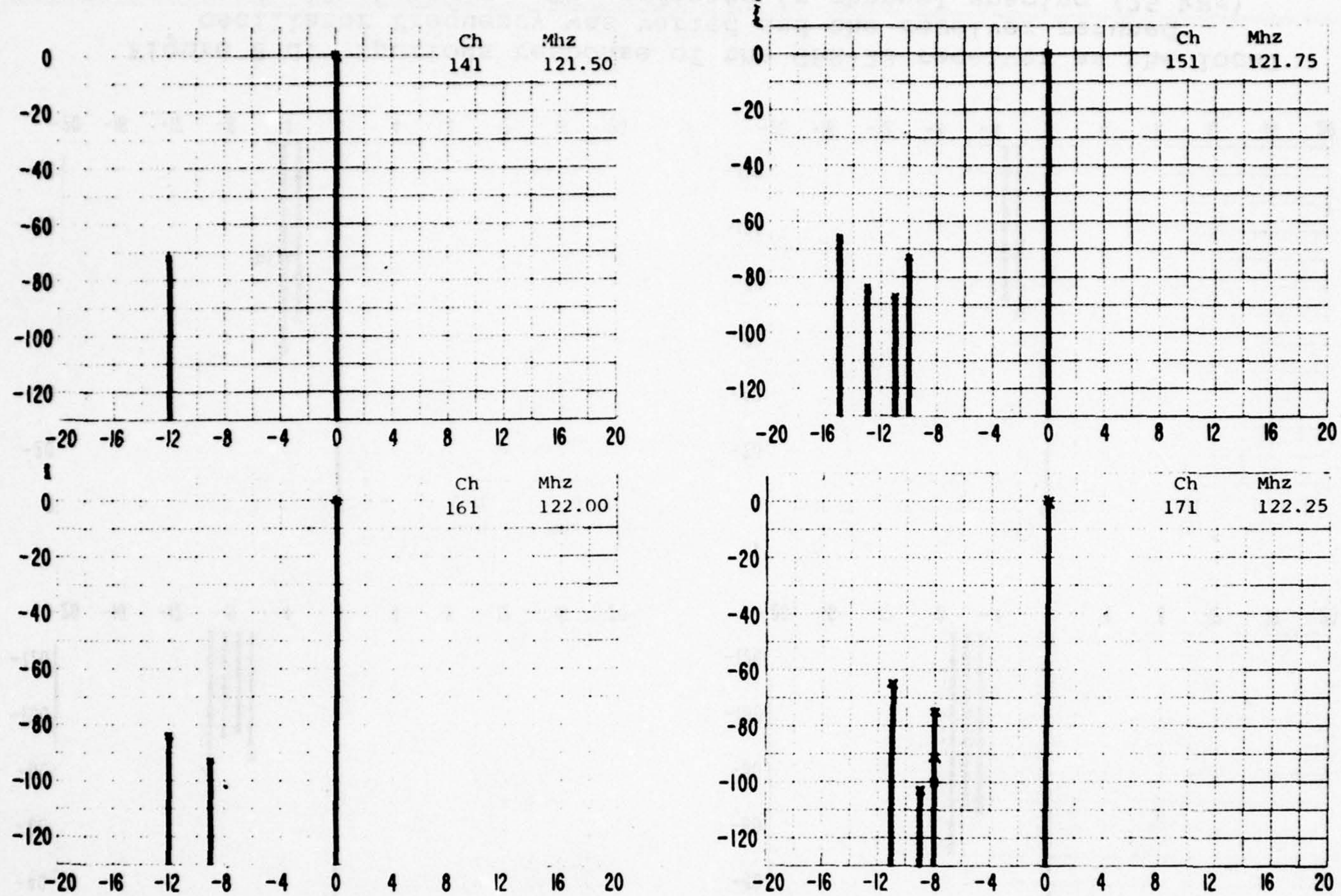


Figure 8 c. Spurious response of the GRR-23 receiver as the local oscillator frequency was varied and the receiver retuned every 10 channels. The ordinate is channel spacing (25 kHz) and the abscissa is dBm.

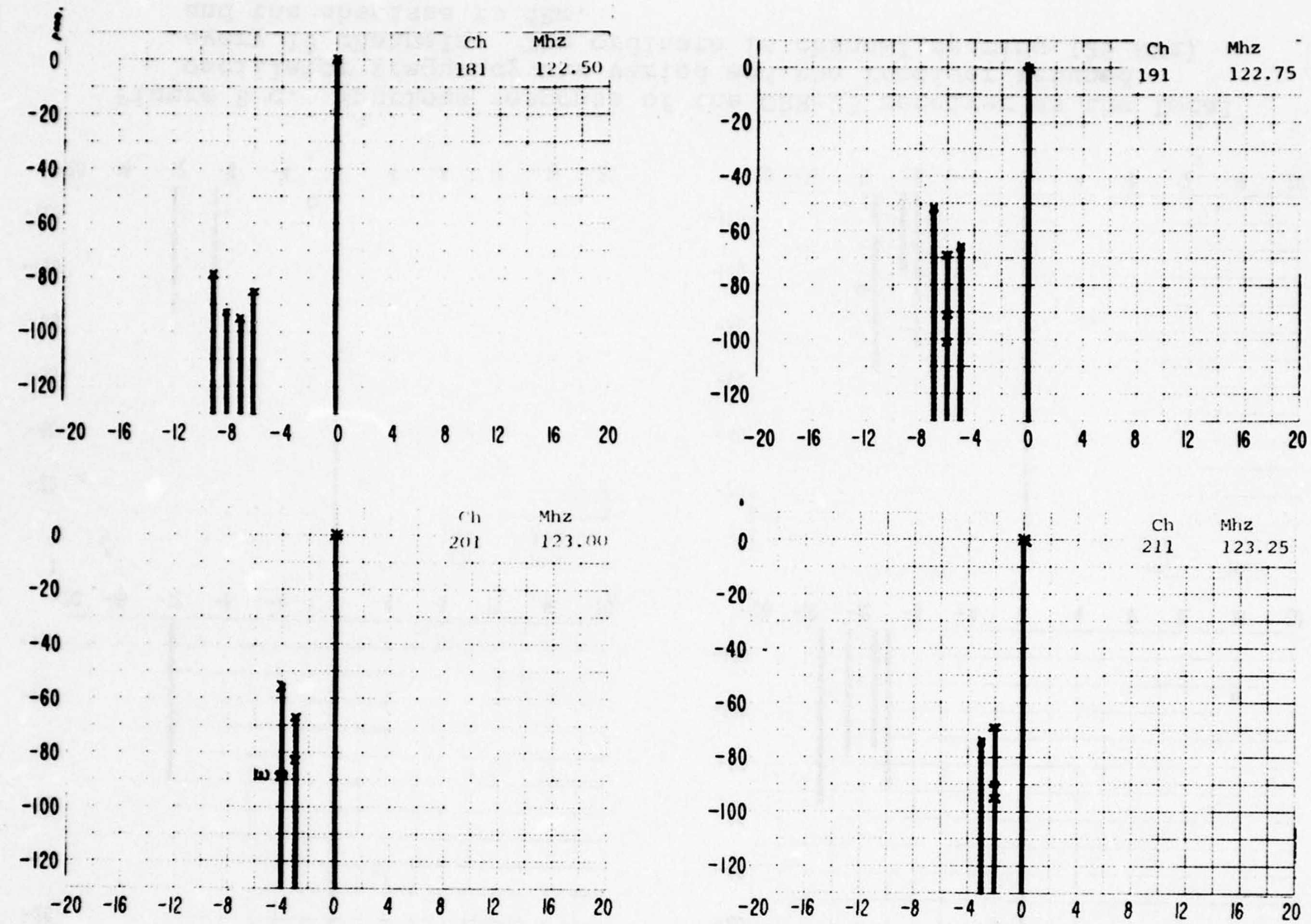


Figure 8 d. Spurious response of the GRR-23 receiver as the local oscillator frequency was varied and the receiver retuned every 10 channels. The ordinate is channel spacing (25 kHz) and the abscissa is dBm.

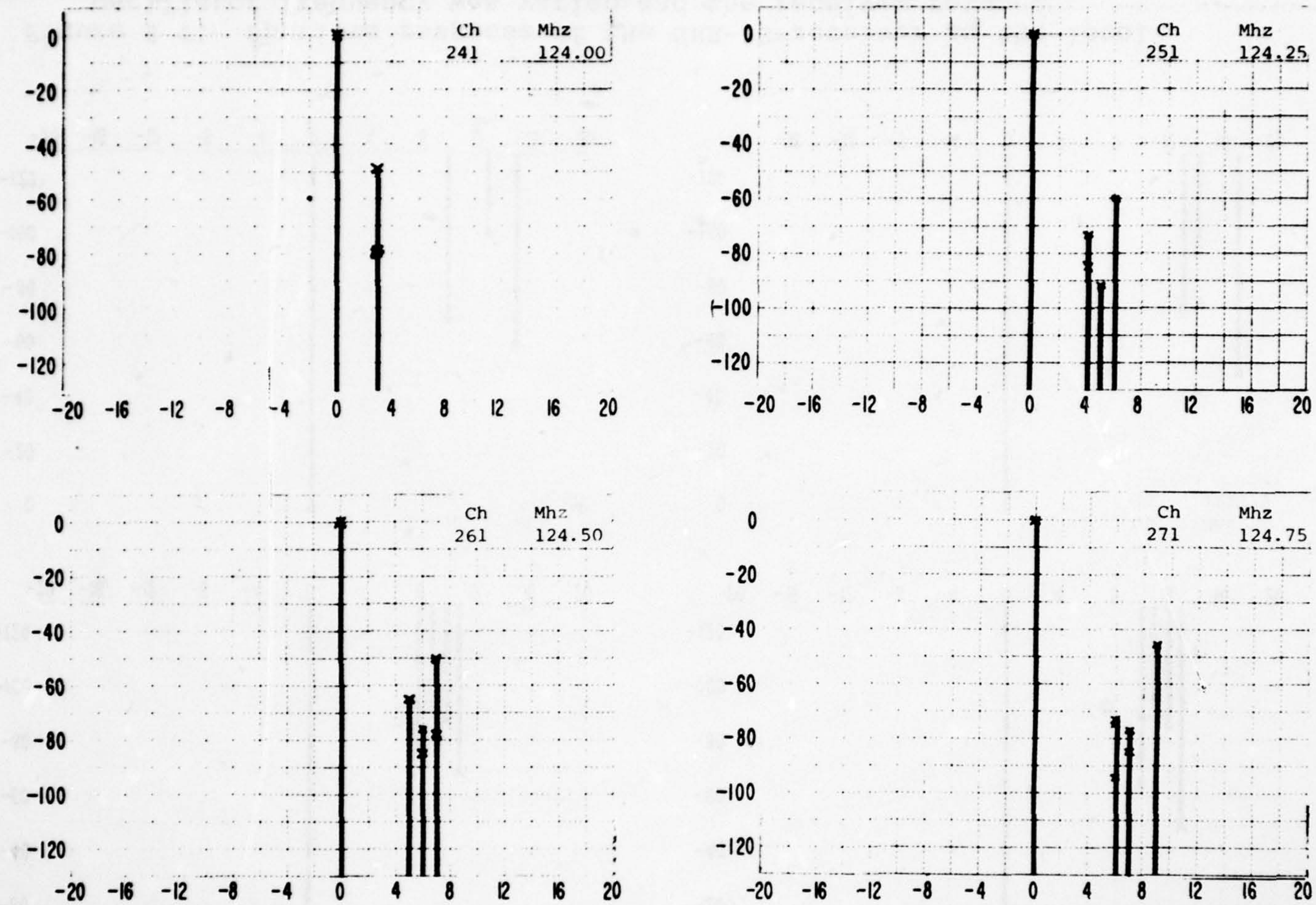


Figure 8 e. Spurious response of the GRR-23 receiver as the local oscillator frequency was varied and the receiver retuned every 10 channels. The ordinate is channel spacing (25 kHz) and the abscissa is dBm.

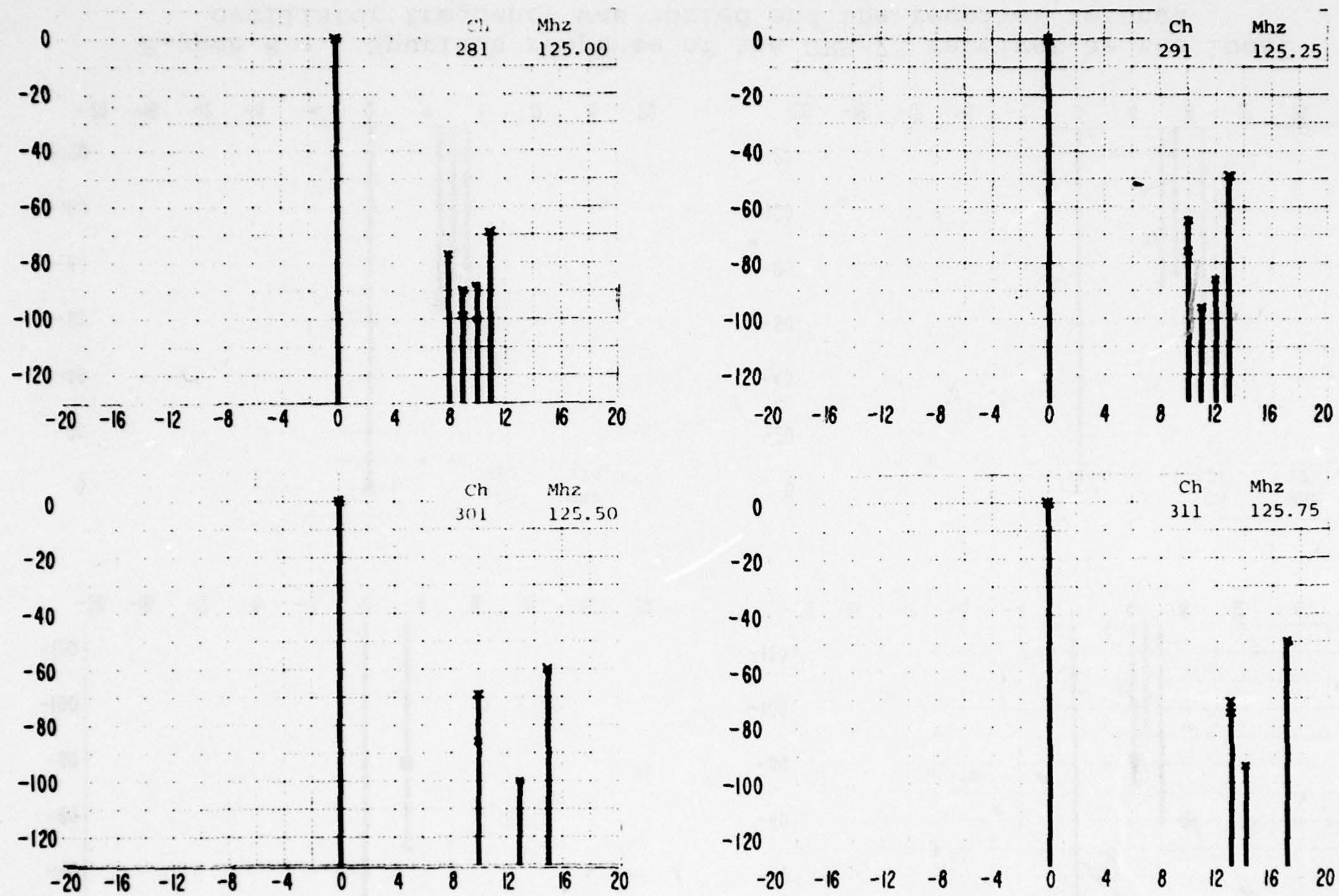


Figure 8 f. Spurious response of the GRR-23 receiver as the local oscillator frequency was varied and the receiver retuned every 10 channels. The ordinate is channel spacing (25 kHz) and the abscissa is dBm.

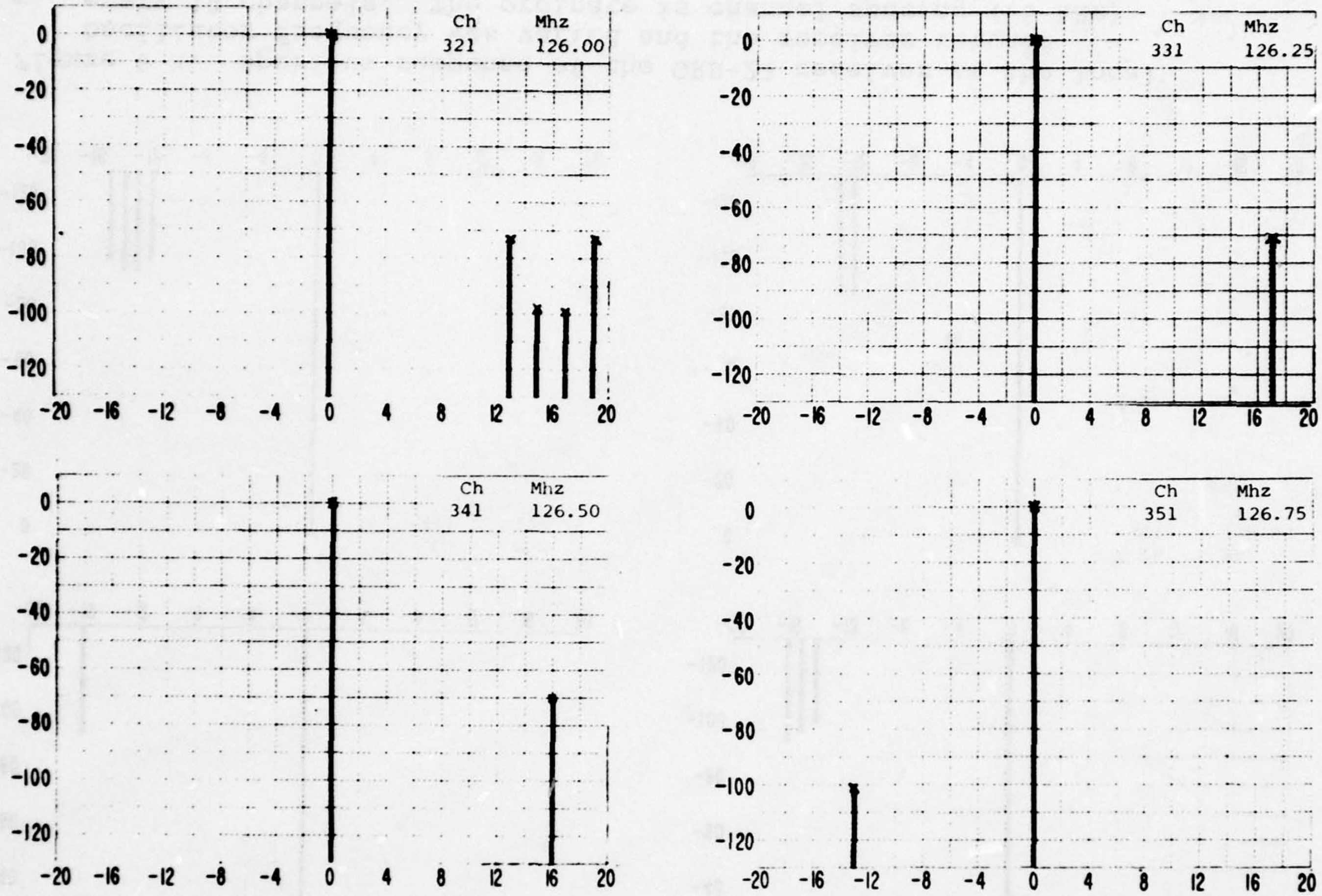


Figure 8 g. Spurious response of the GRR-23 receiver as the local oscillator frequency was varied and the receiver retuned every 10 channels. The ordinate is channel spacing (25 kHz) and the abscissa is dBm.

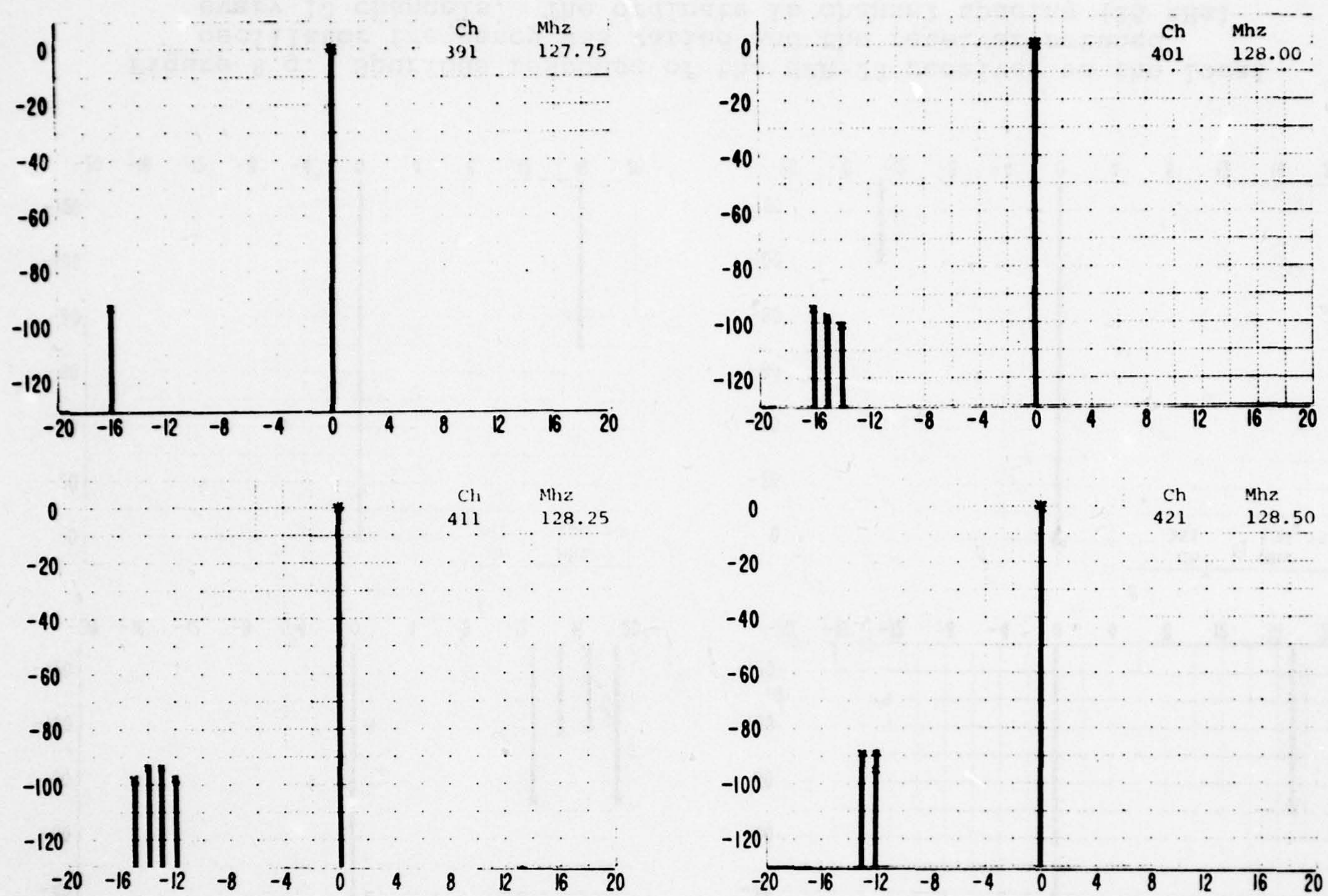


Figure 8 h. Spurious response of the GRR-23 receiver as the local oscillator frequency was varied and the receiver retuned every 10 channels. The ordinate is channel spacing (25 kHz) and the abscissa is dBm.

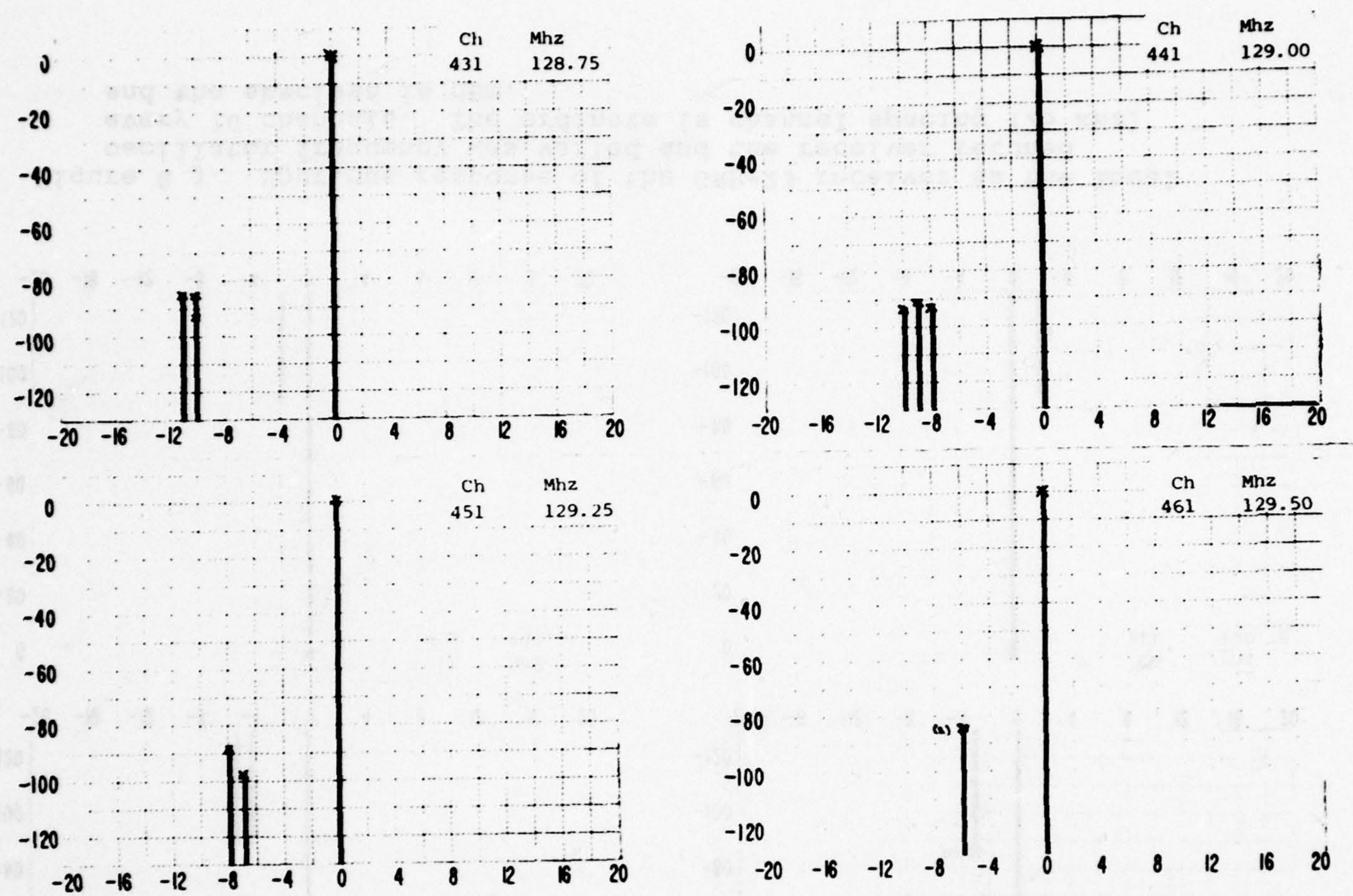


Figure 8 i. Spurious response of the GRR-23 receiver as the local oscillator frequency was varied and the receiver retuned every 10 channels. The ordinate is channel spacing (25 kHz) and the abscissa is dBm.

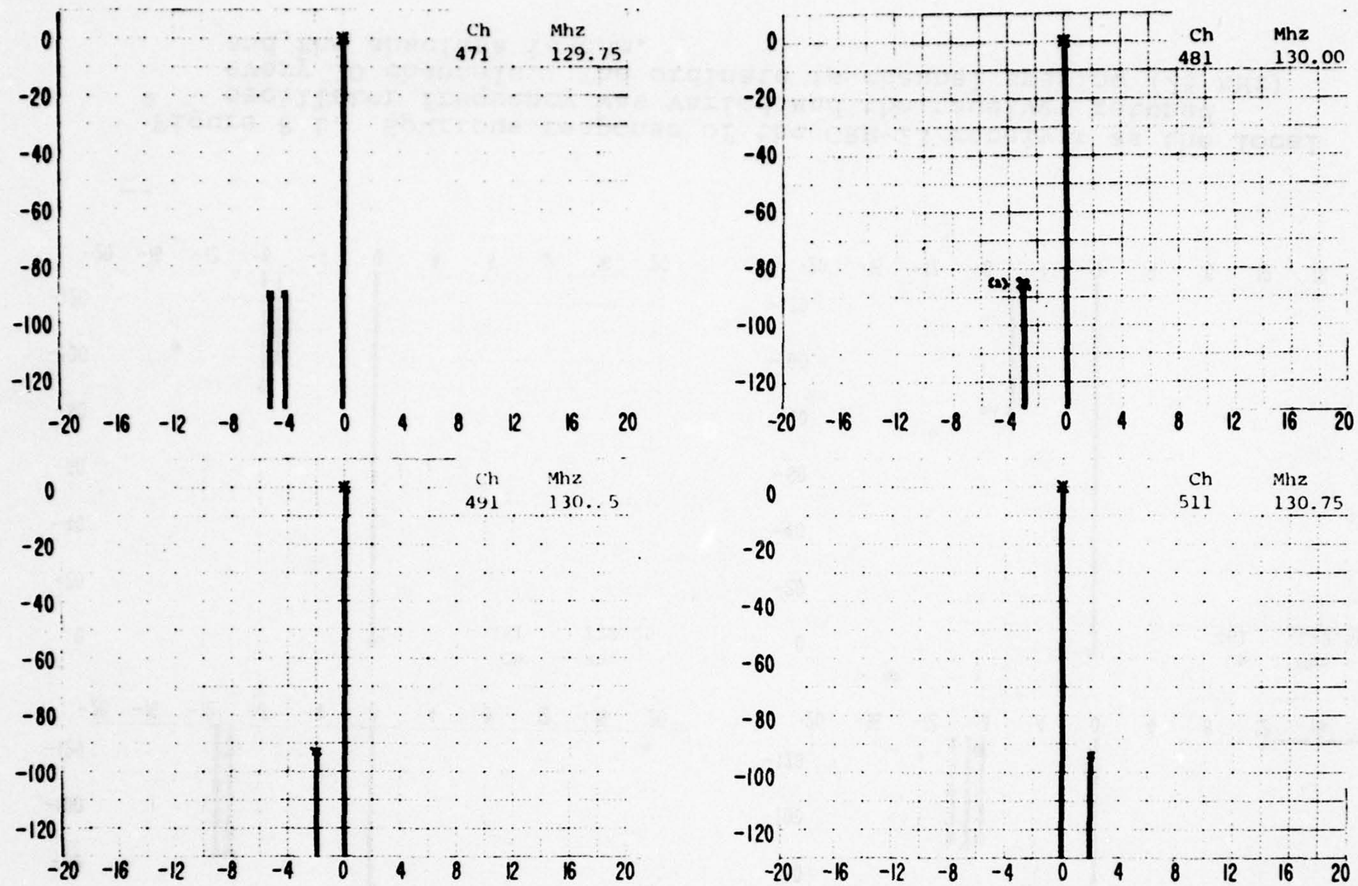


Figure 8 j. Spurious response of the GRR-23 receiver as the local oscillator frequency was varied and the receiver retuned every 10 channels. The ordinate is channel spacing (25 kHz) and the abscissa is dBm.

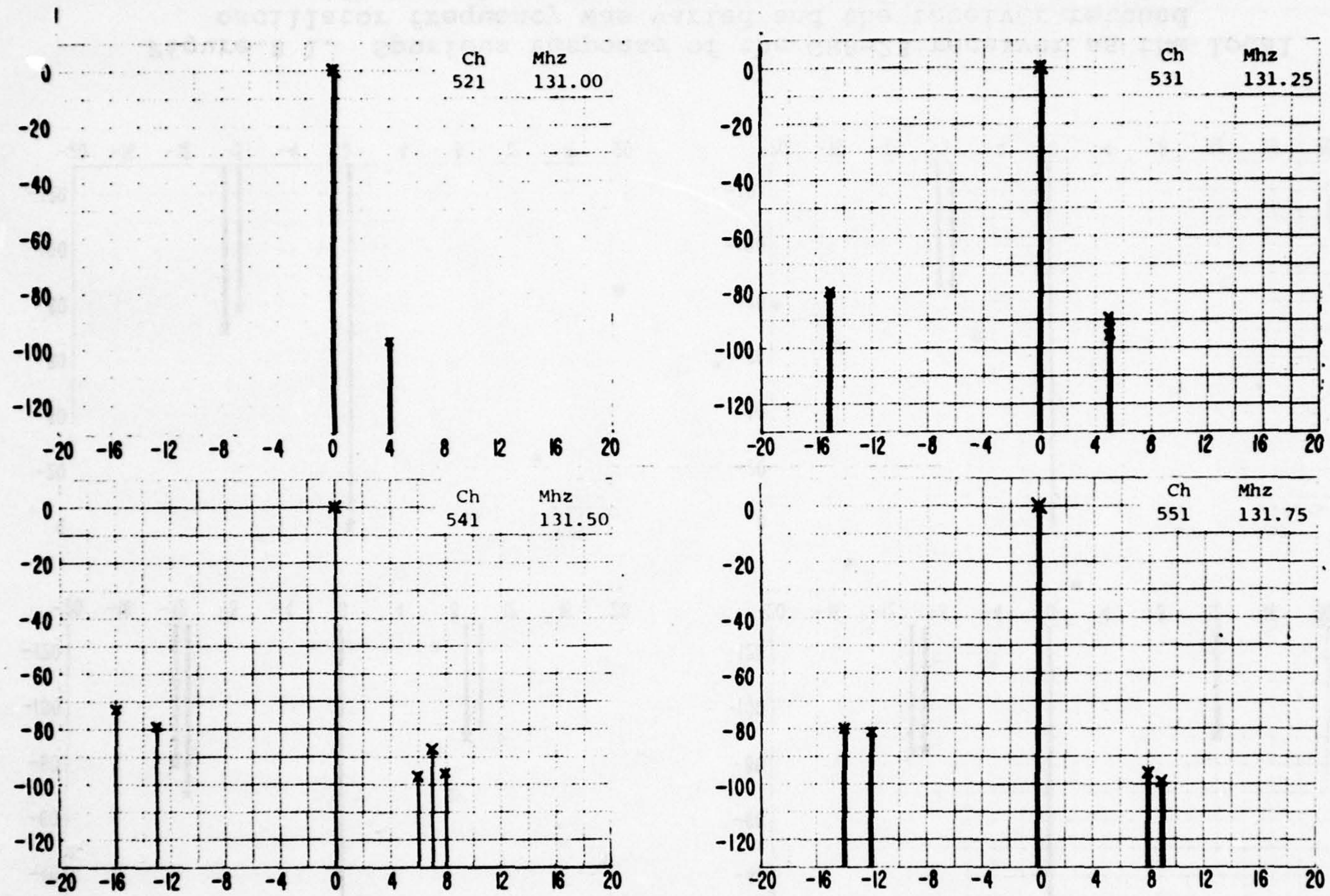


Figure 8 k. Spurious response of the GRR-23 receiver as the local oscillator frequency was varied and the receiver retuned every 10 channels. The ordinate is channel spacing (25 kHz) and the abscissa is dBm.

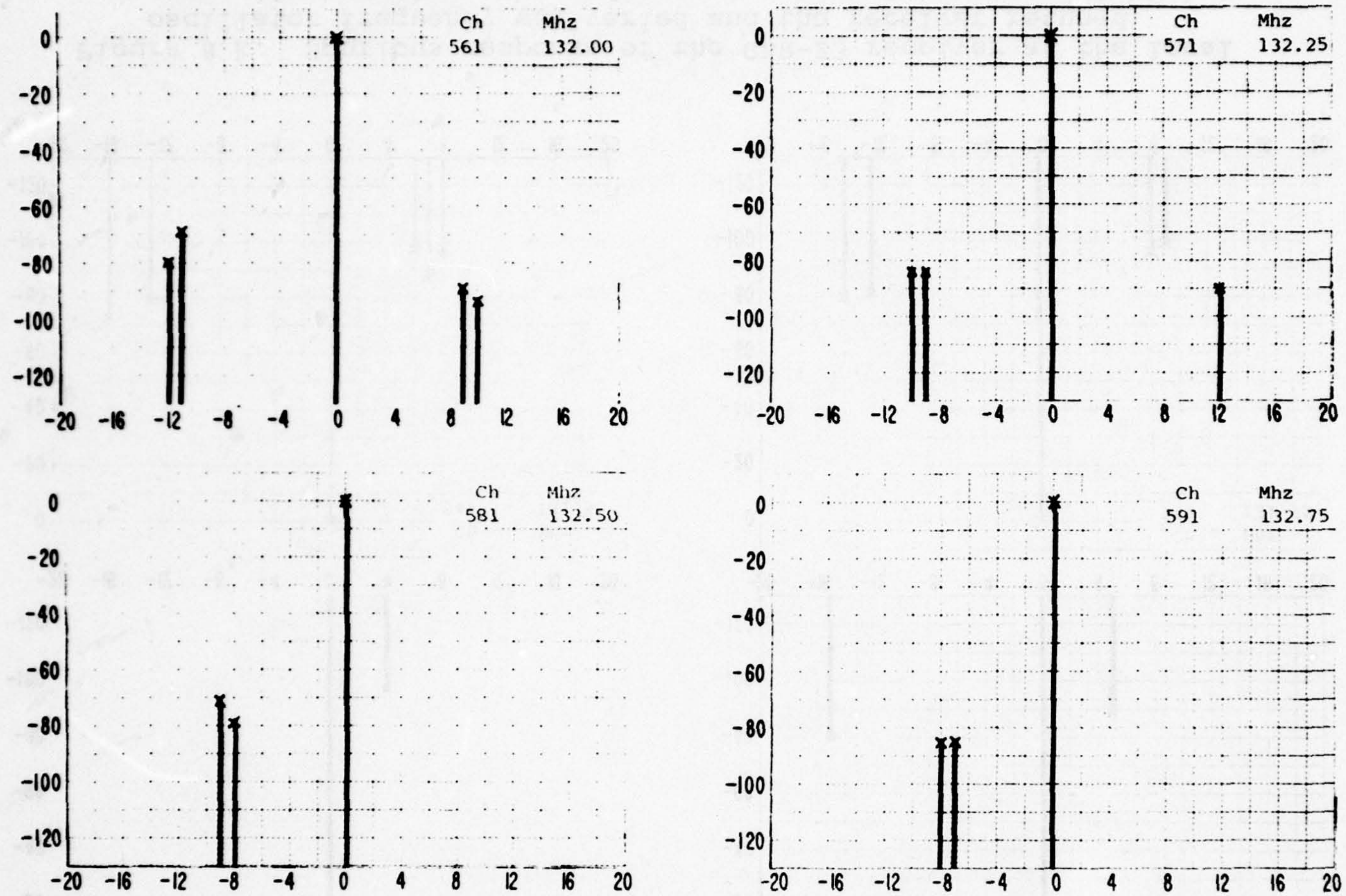


Figure 8 1. Spurious response of the GRR-23 receiver as the local oscillator frequency was varied and the receiver retuned every 10 channels. The ordinate is channel spacing (25 kHz) and the abscissa is dBm.

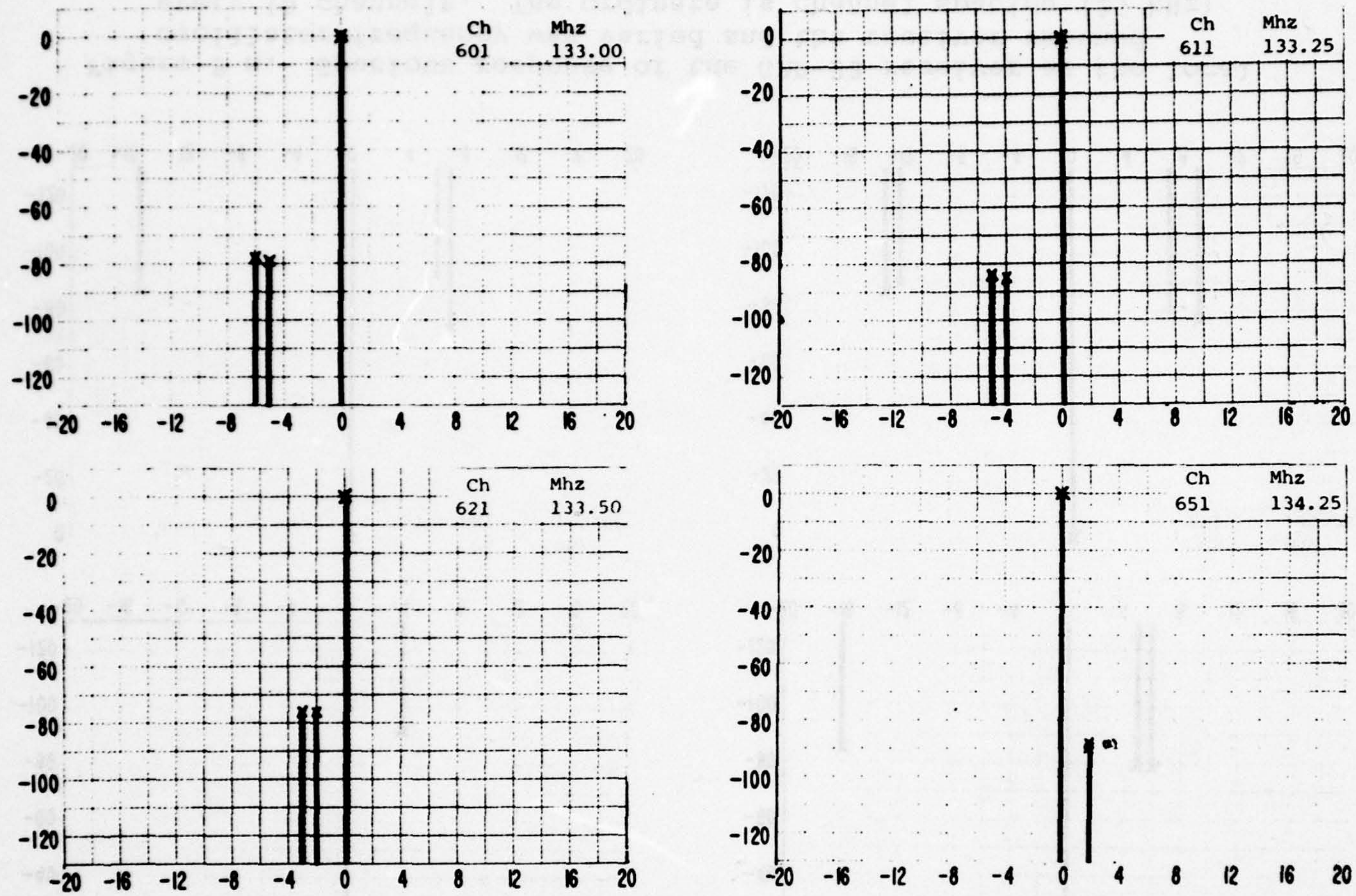


Figure 8 m. Spurious response of the GRR-23 receiver as the local oscillator frequency was varied and the receiver retuned every 10 channels. The ordinate is channel spacing (25 kHz) and the abscissa is dBm.

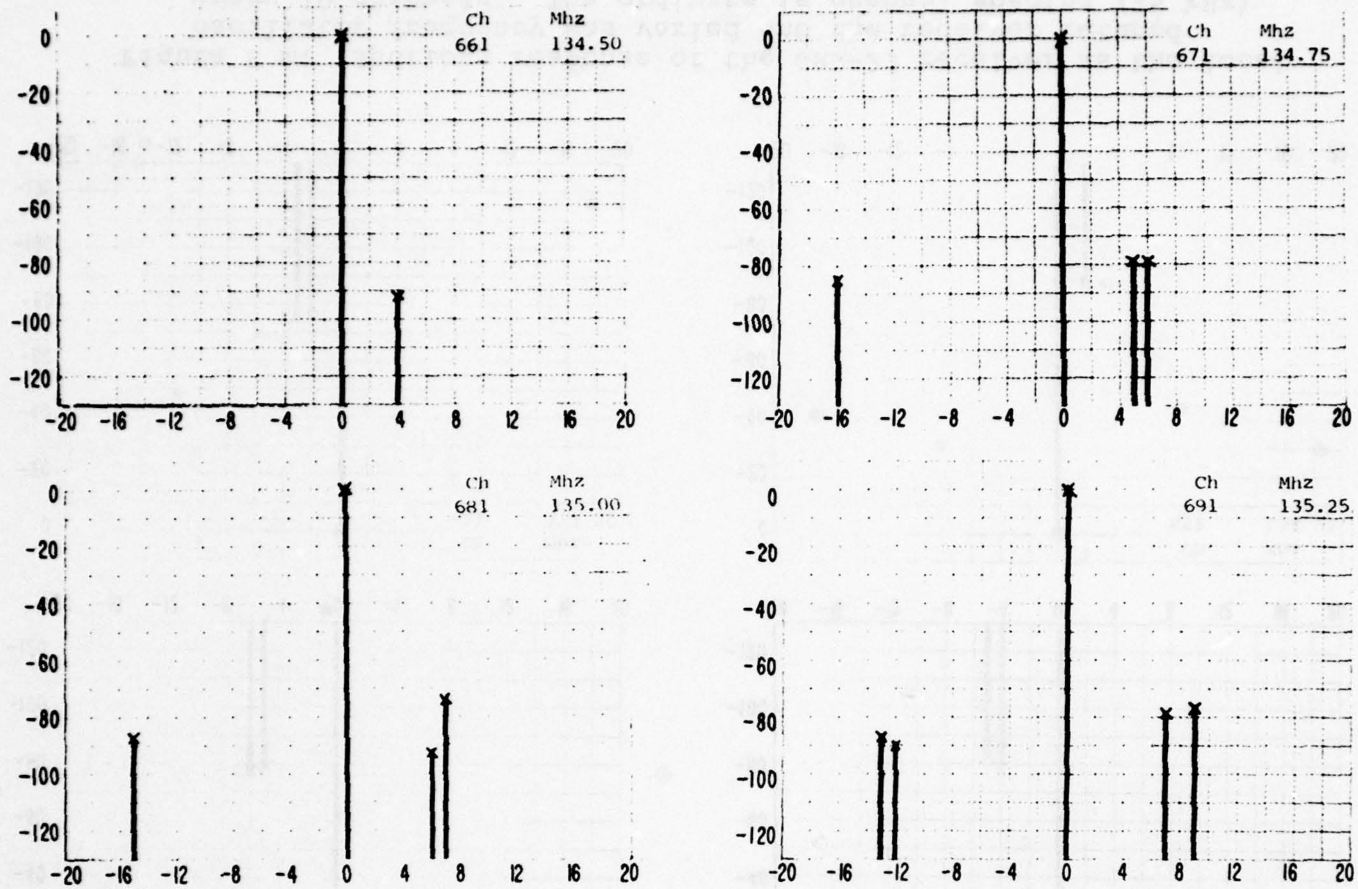
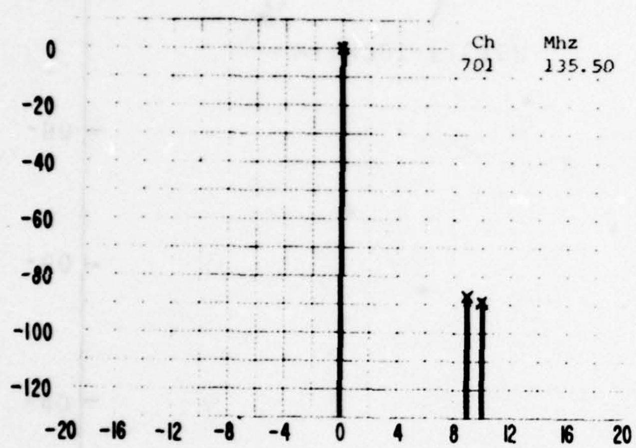


Figure 8 n. Spurious response of the GRR-23 receiver as the local oscillator frequency was varied and the receiver retuned every 10 channels. The ordinate is channel spacing (25 kHz) and the abscissa is dBm.



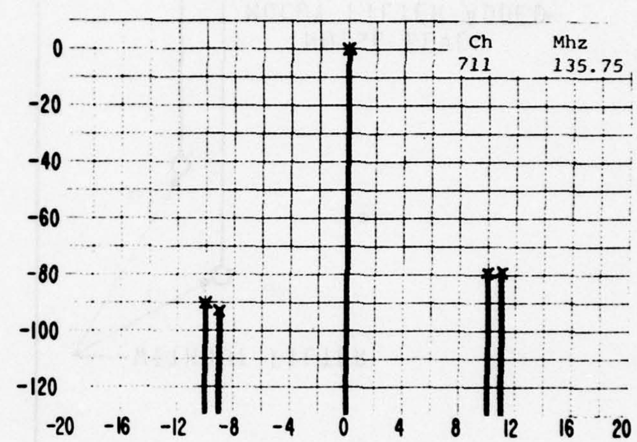


Figure 8 o. Spurious response of the GRR-23 receiver as the local oscillator frequency was varied and the receiver retuned every 10 channels. The ordinate is channel spacing (25 kHz) and the abscissa is dBm.

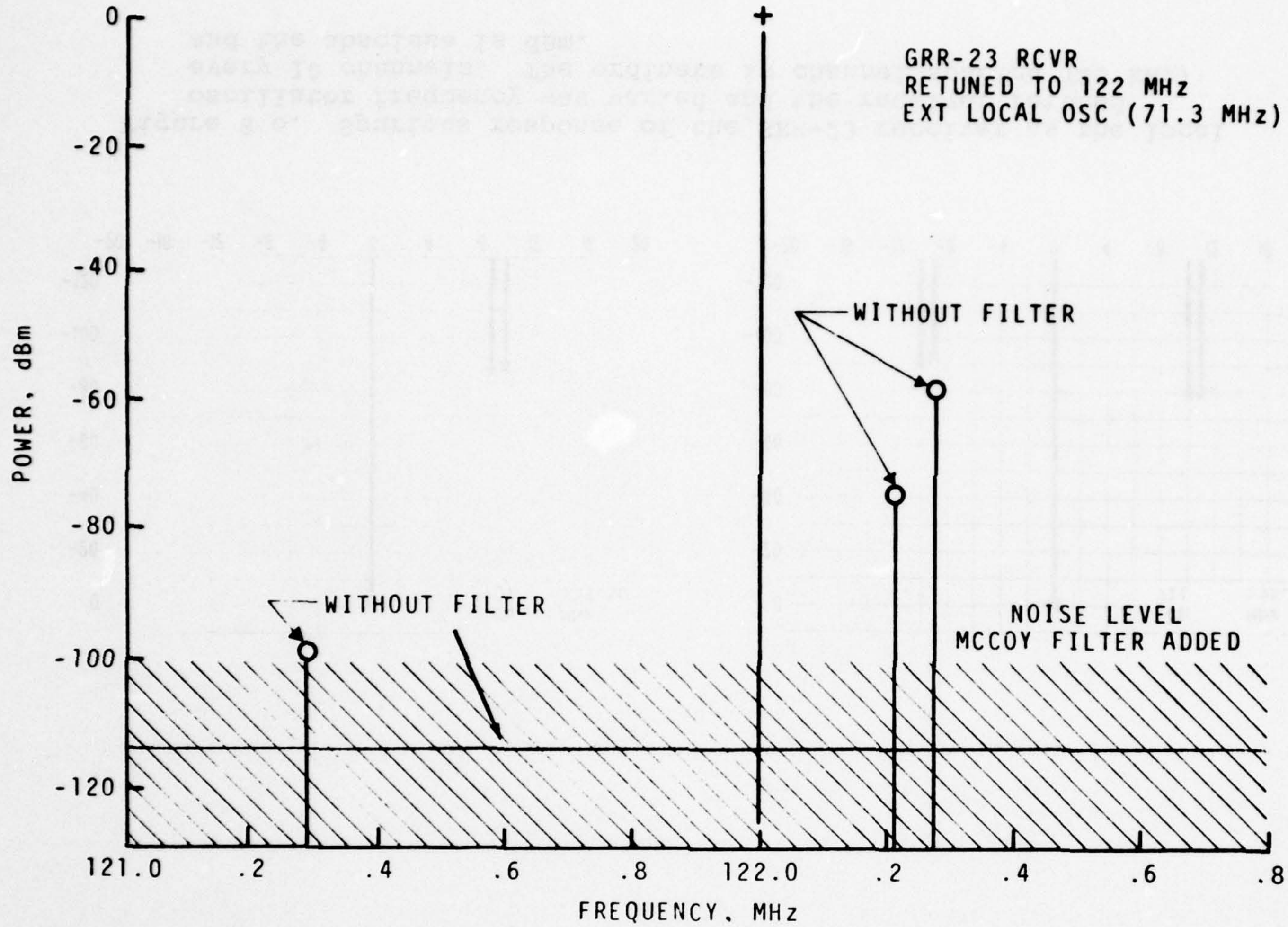


Figure 9. Spurious response of the GRR-23 receiver with and without filter.

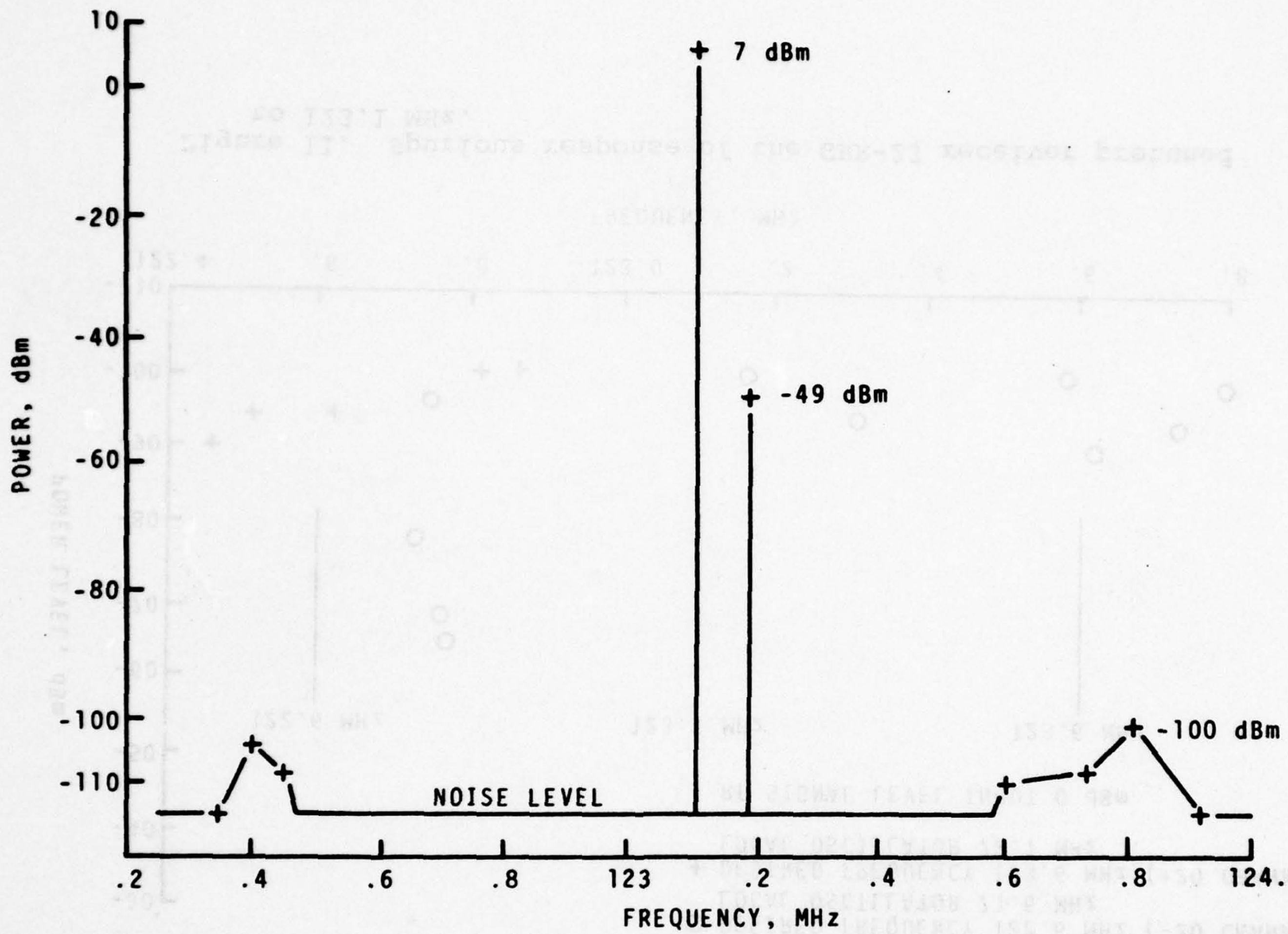


Figure 10. Spurious response of the GRR-23 receiver at 123.1 MHz.

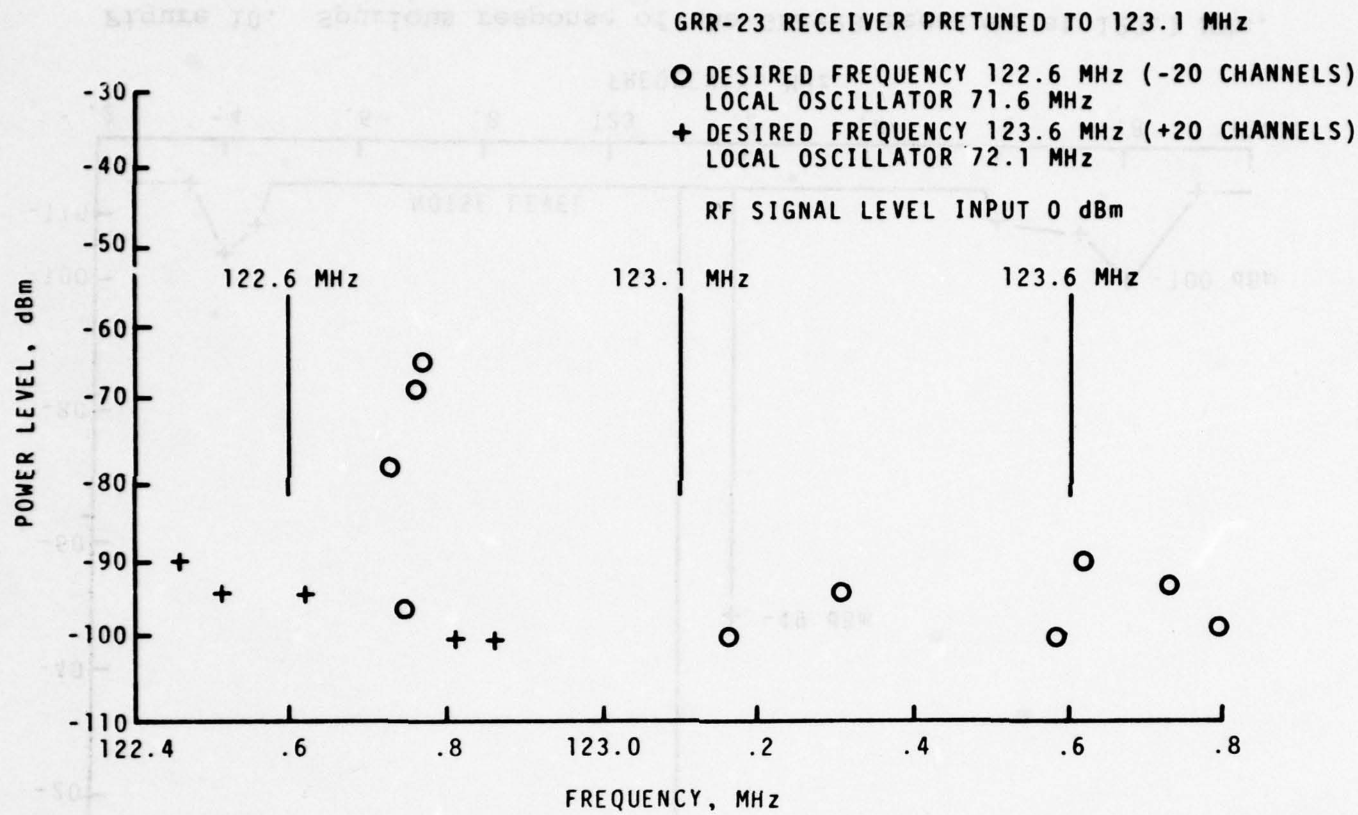


Figure 11. Spurious response of the GRR-23 receiver pretuned to 123.1 MHz.

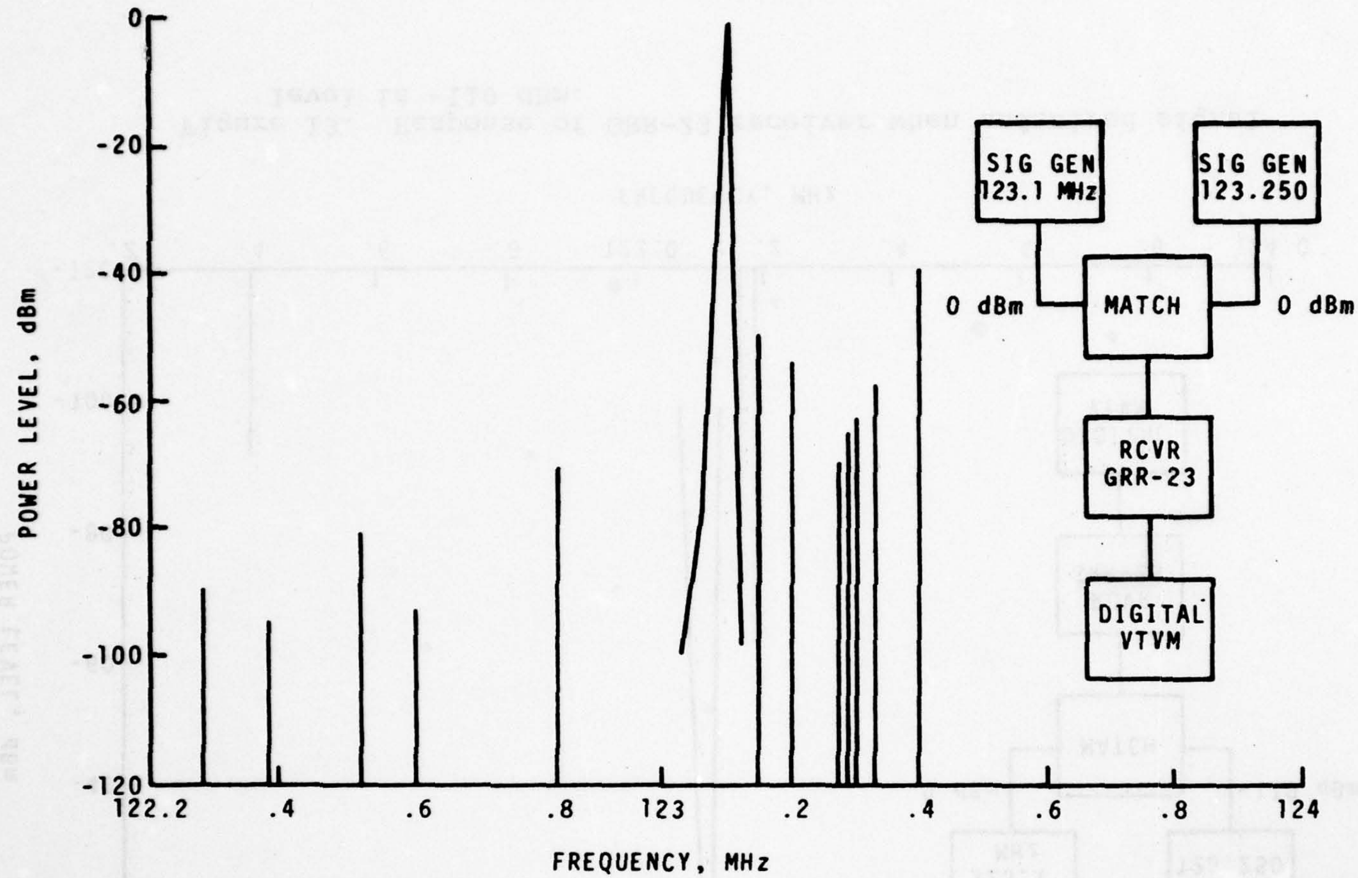


Figure 12. Response of the GRR-23 receiver when undesired signal level is 0 dBm.

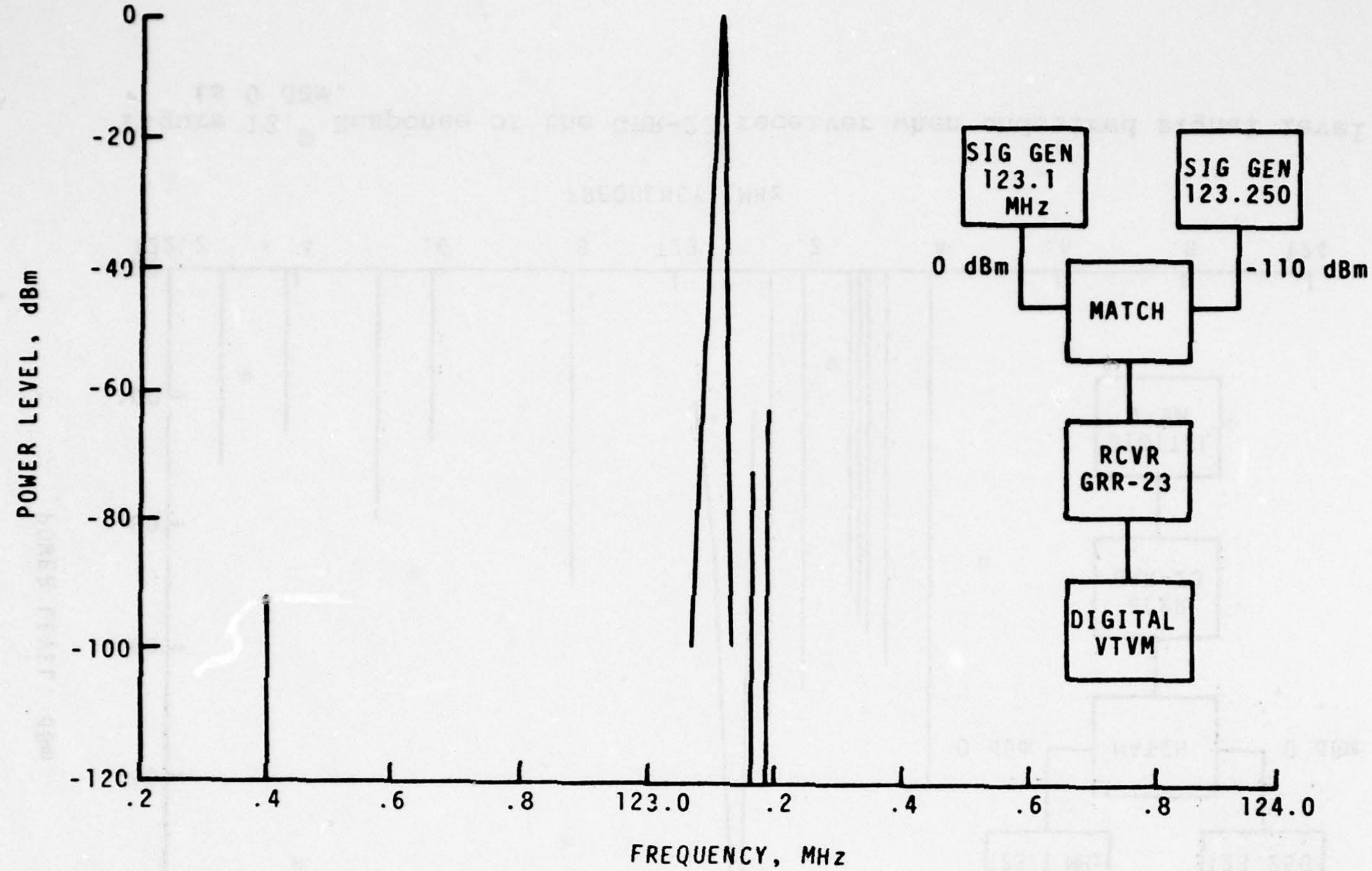


Figure 13. Response of GRR-23 receiver when undesired signal level is -110 dBm.

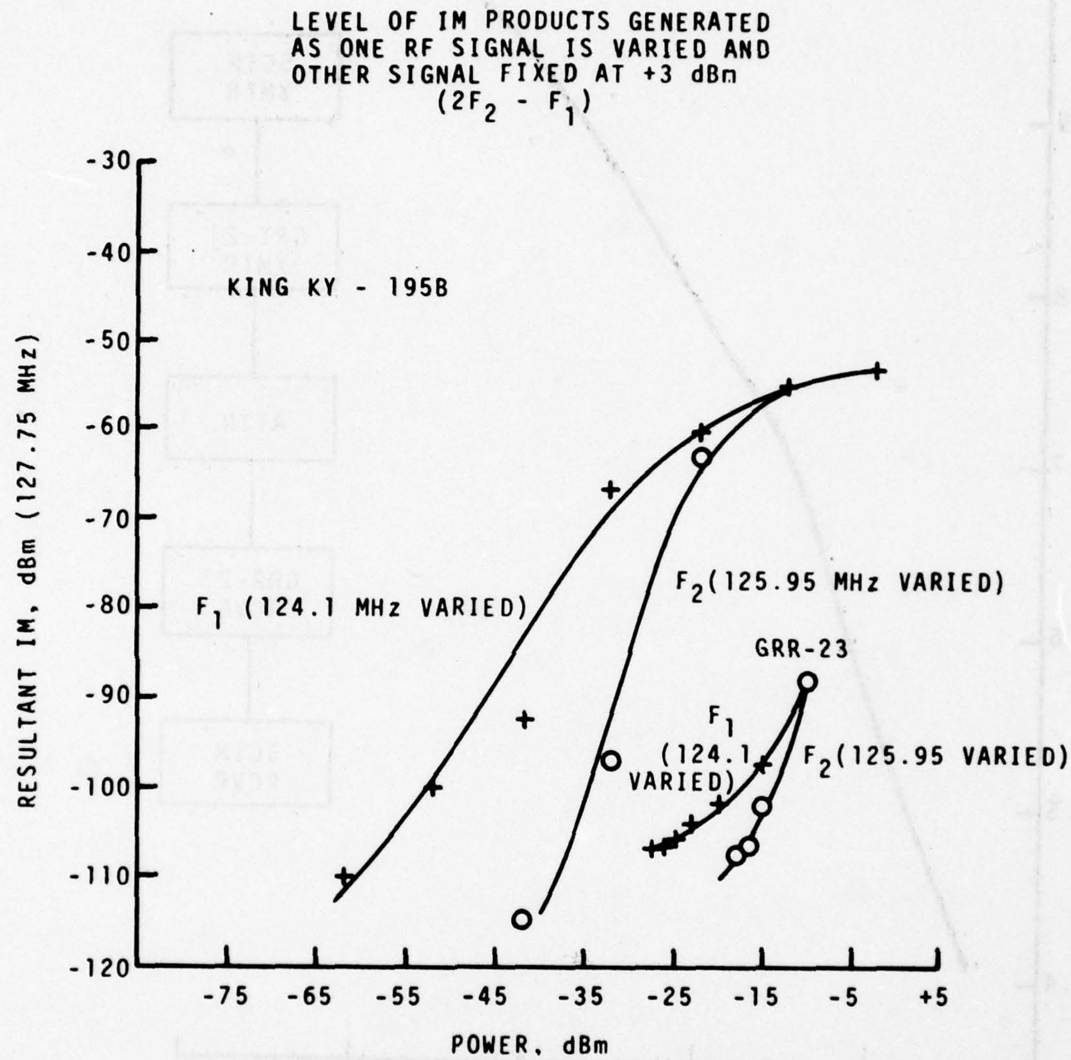


Figure 14. Level of IM products generated as one rf signal is varied and the other signal is fixed at +3 dBm.

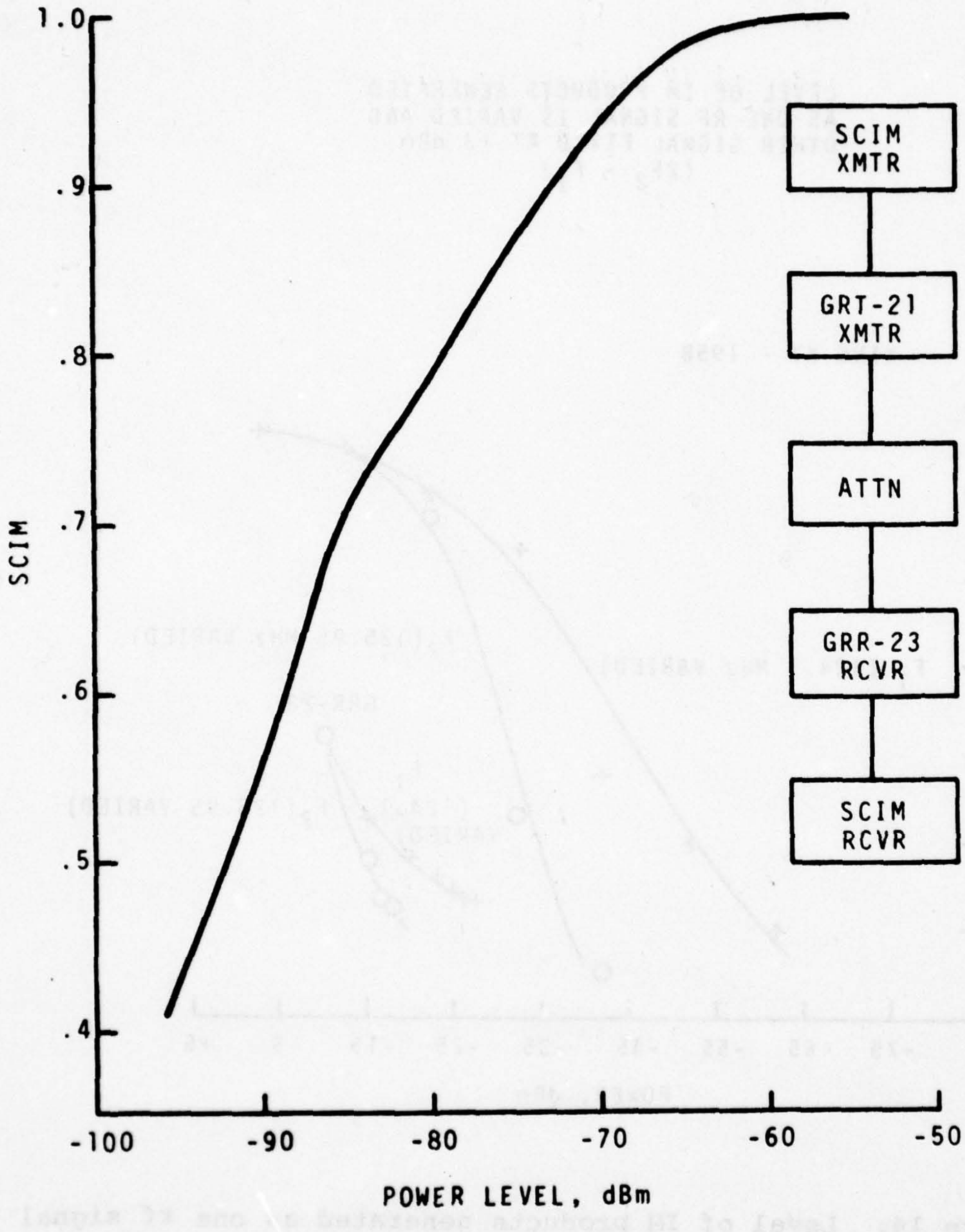


Figure 15. Radio frequency power level versus SCIM reading of the GRT-21 and GRR-23 receiver combination.

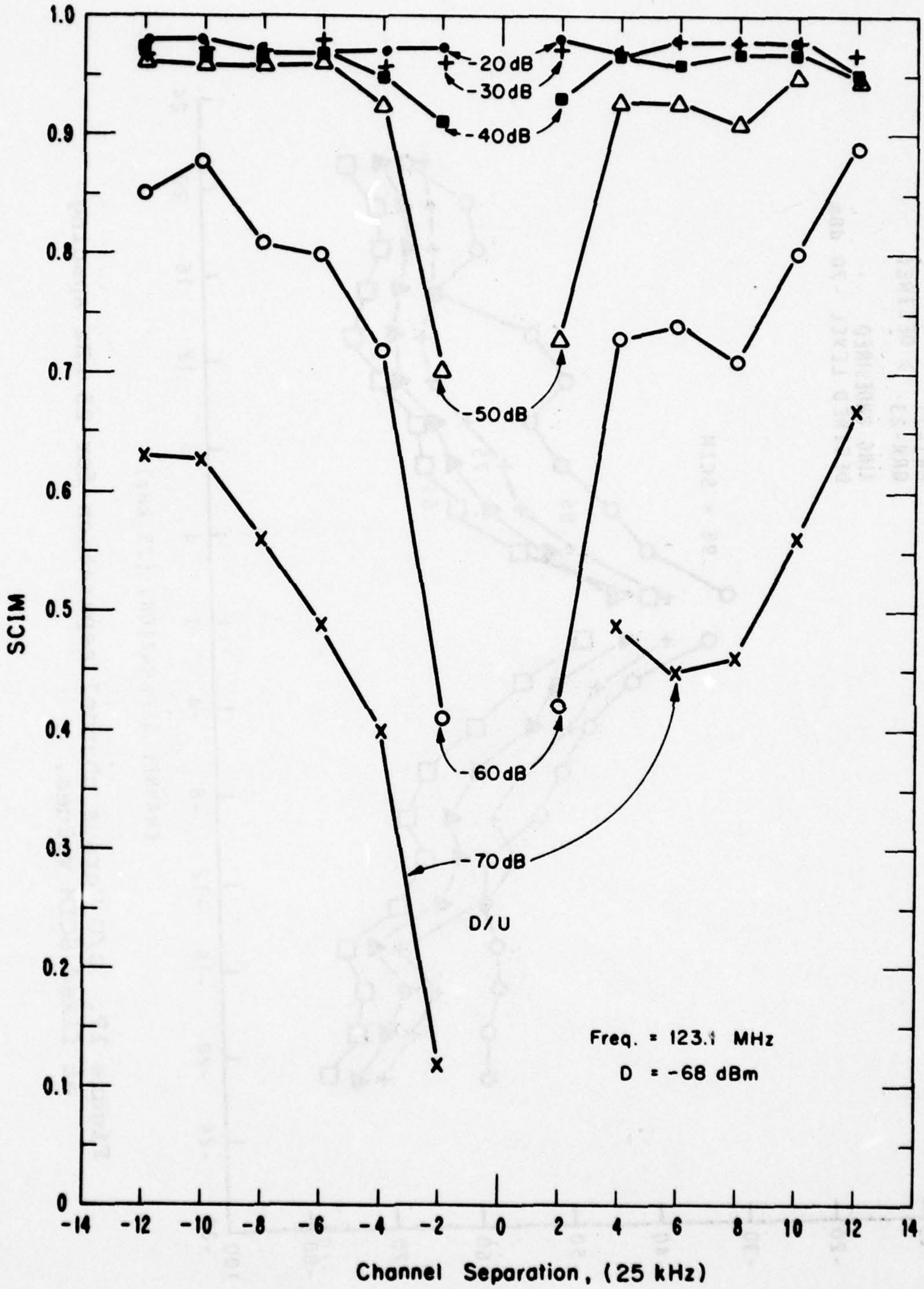


Figure 16. Desired to undesired (D/U) ratios versus SCIM readings for channel separation.

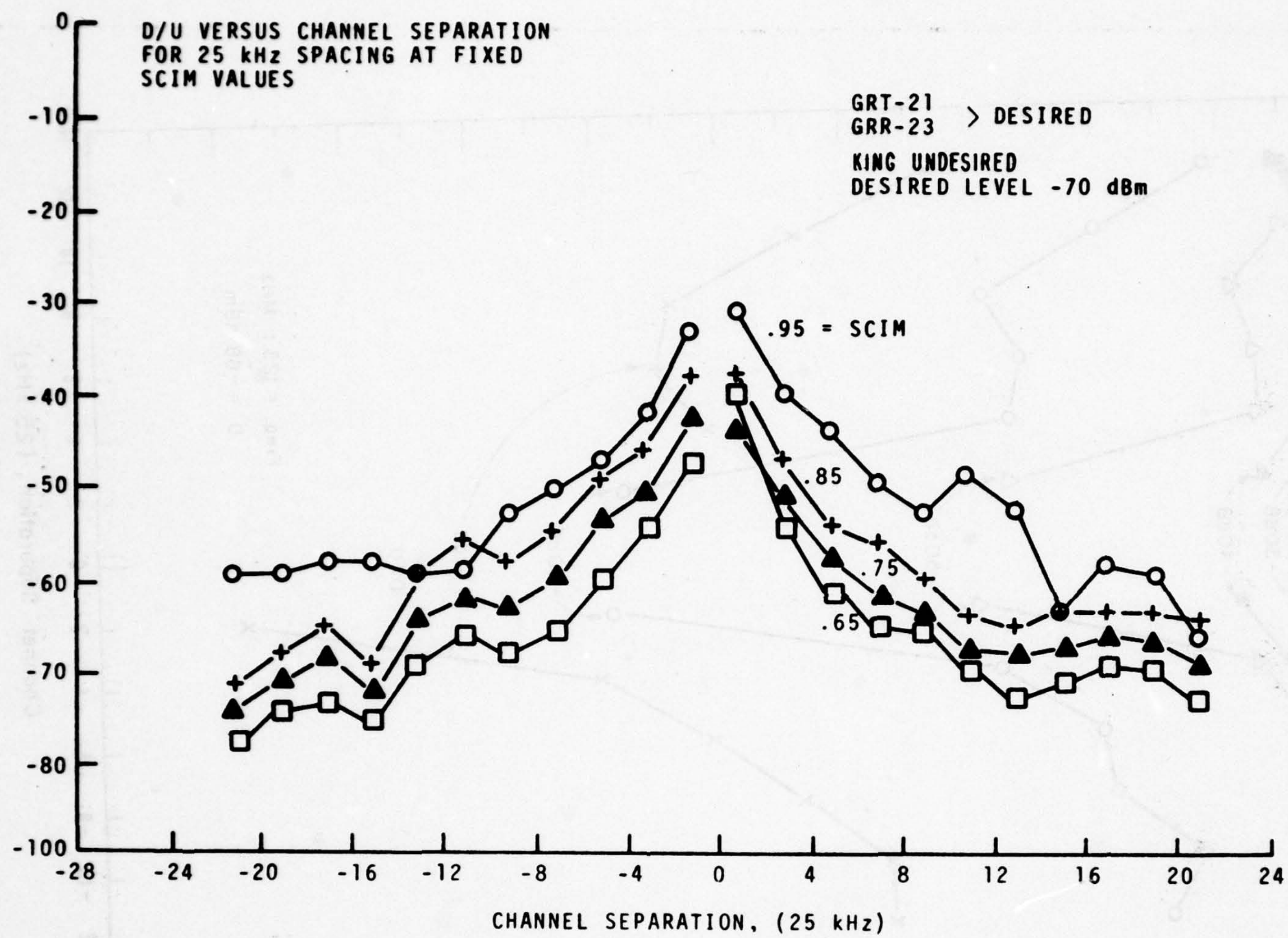


Figure 17. D/U Versus channel separation for 25 kHz spacing at fixed SCIM values.

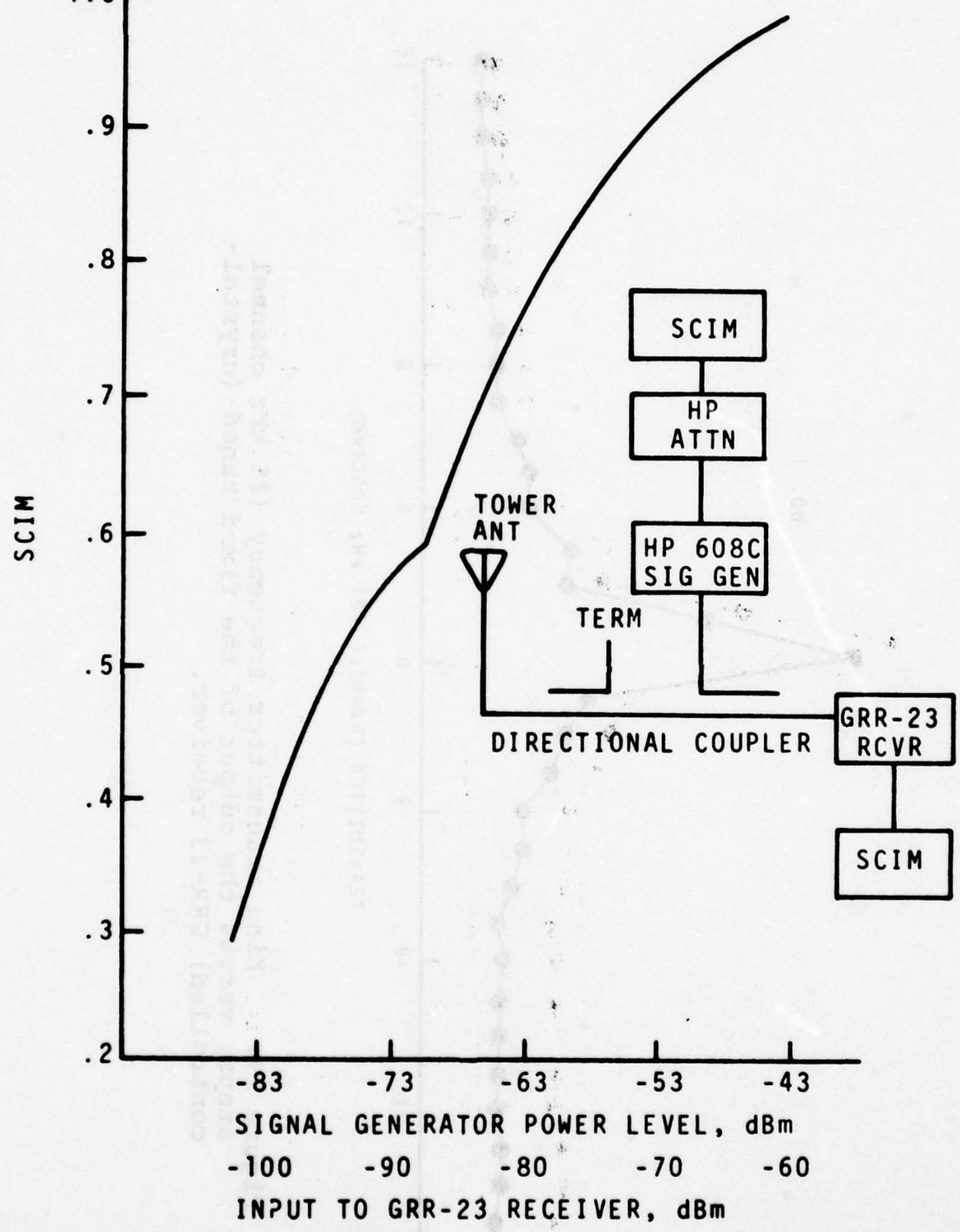


Figure 18. Power level versus SCIM reading for on-site RCAG measurements.

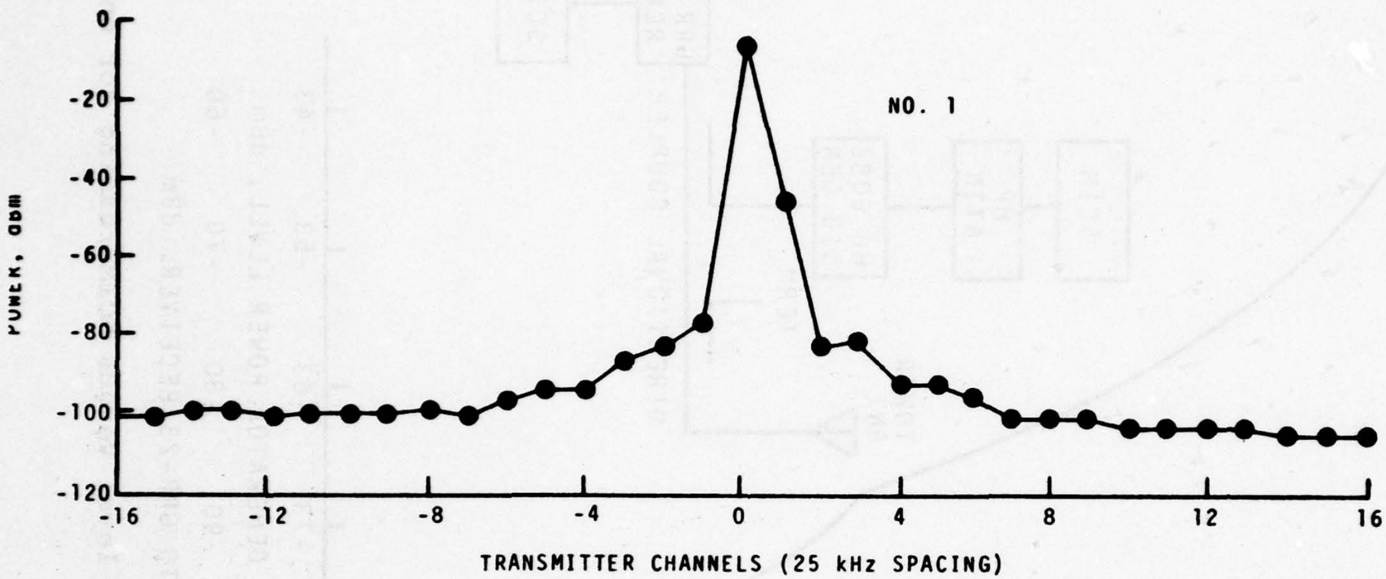


Figure 19. King transmitter frequency (25 kHz channel steps) versus the output of the fixed tuned (crystal-controlled) GRR-23 receiver.

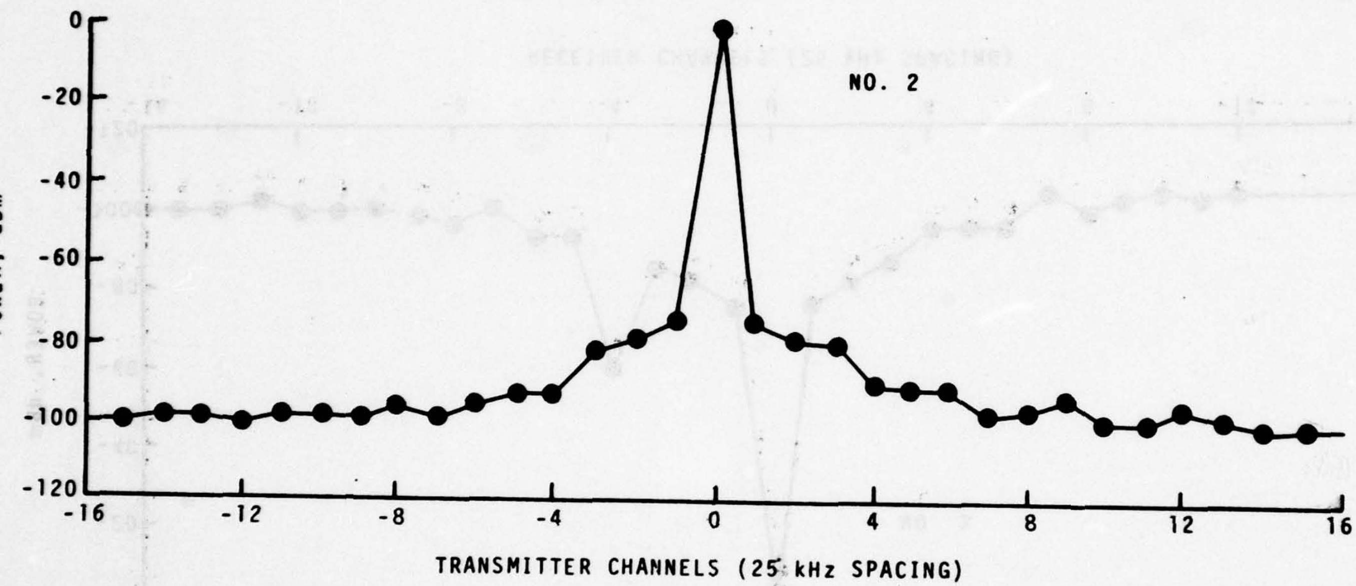


Figure 20. King transmitter frequency varied versus the output of a fixed, tuned local oscillator supplied by a HP 608 C signal generator.

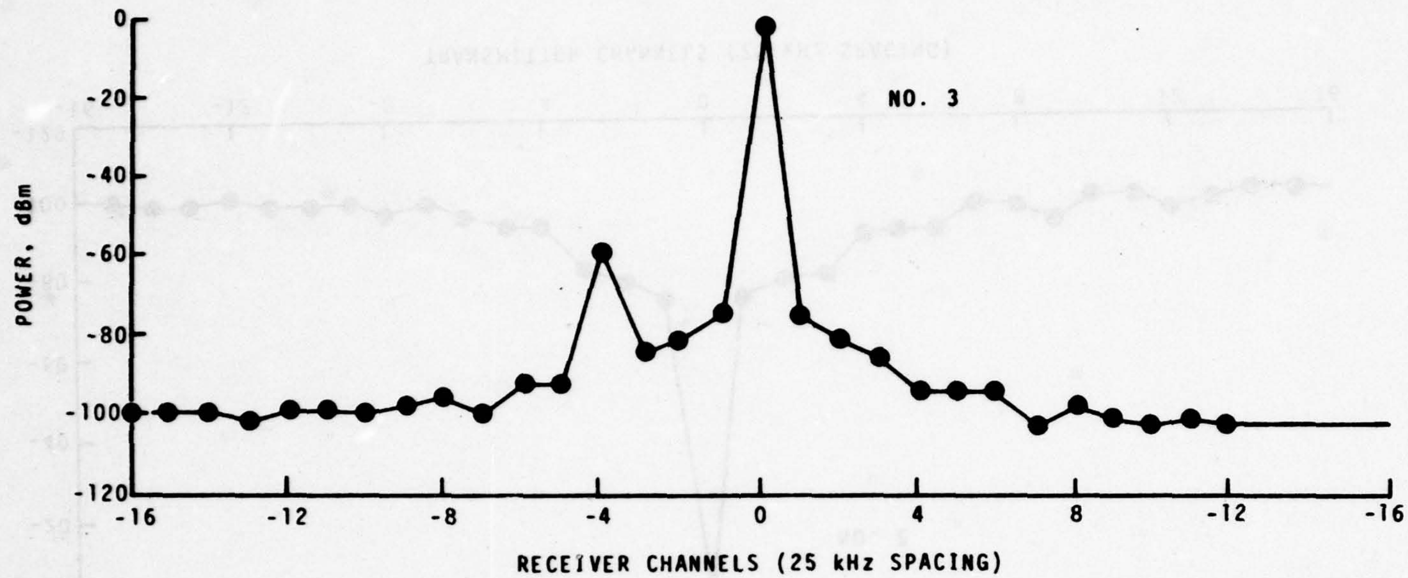


Figure 21. King transmitter frequency fixed versus the output of the receiver (GRR-23) varied plus and minus 20 channels.

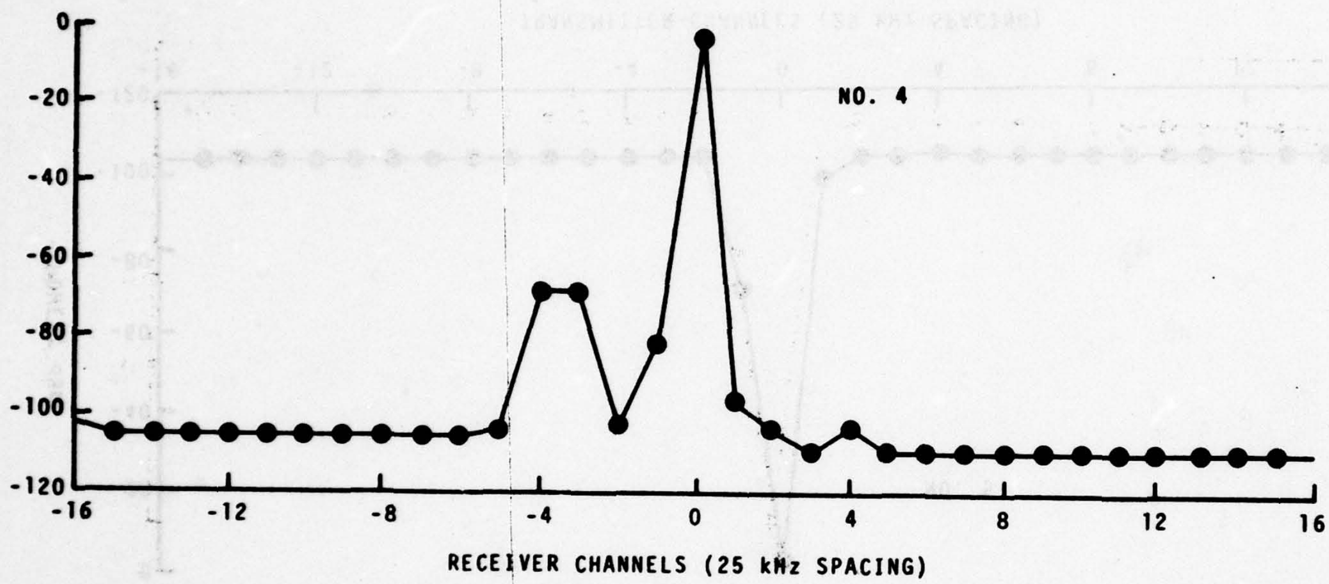


Figure 22. GRT-21 transmitter frequency fixed at 123.1 MHz versus the output of the GRR-23 receiver varied plus and minus 20 channels.

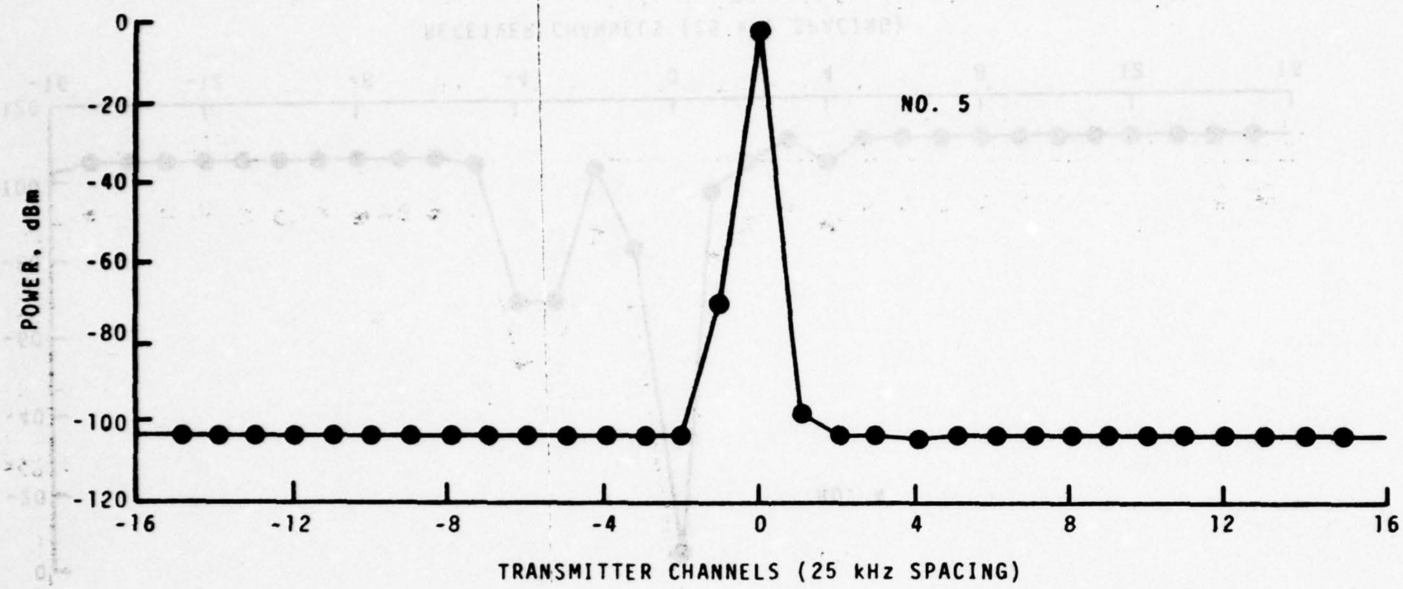


Figure 23. GRT-21 transmitter frequency varied plus and minus 20 channels from 123.1 MHz versus output of the GRR-23 receiver (fixed). No modulation.

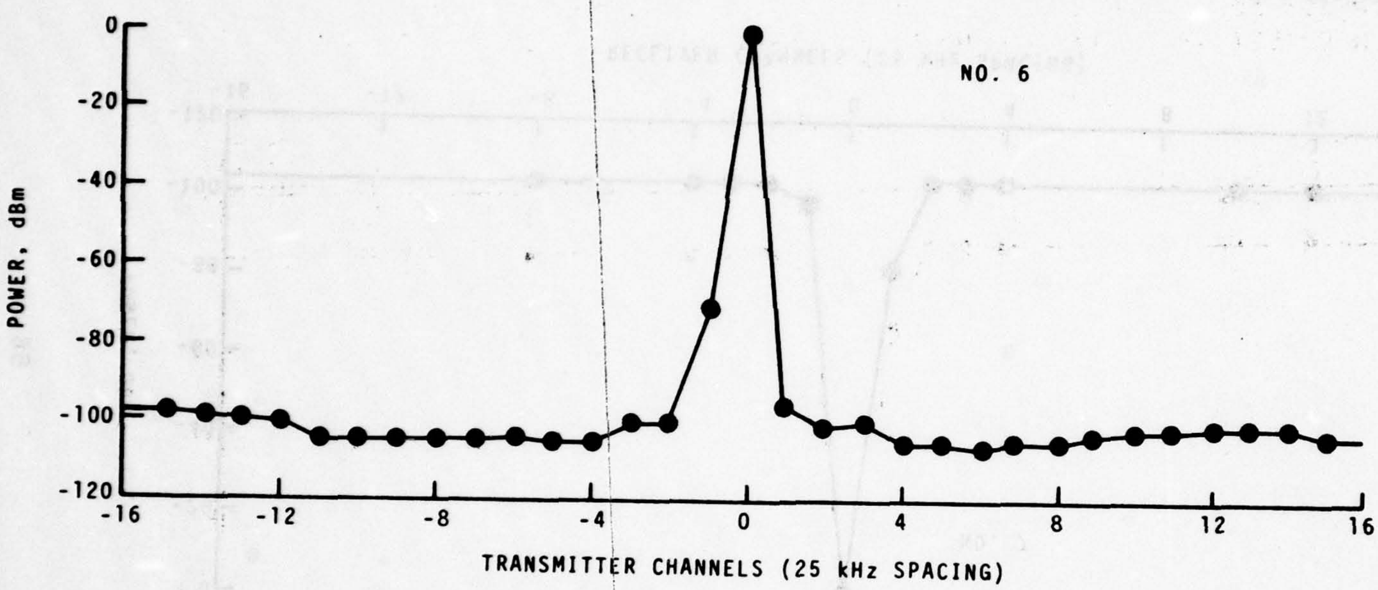


Figure 24. GRT-21 transmitter with 1 kHz modulation and varied plus and minus 20 channels from 123.1 MHz versus output of the GRR-23 receiver.

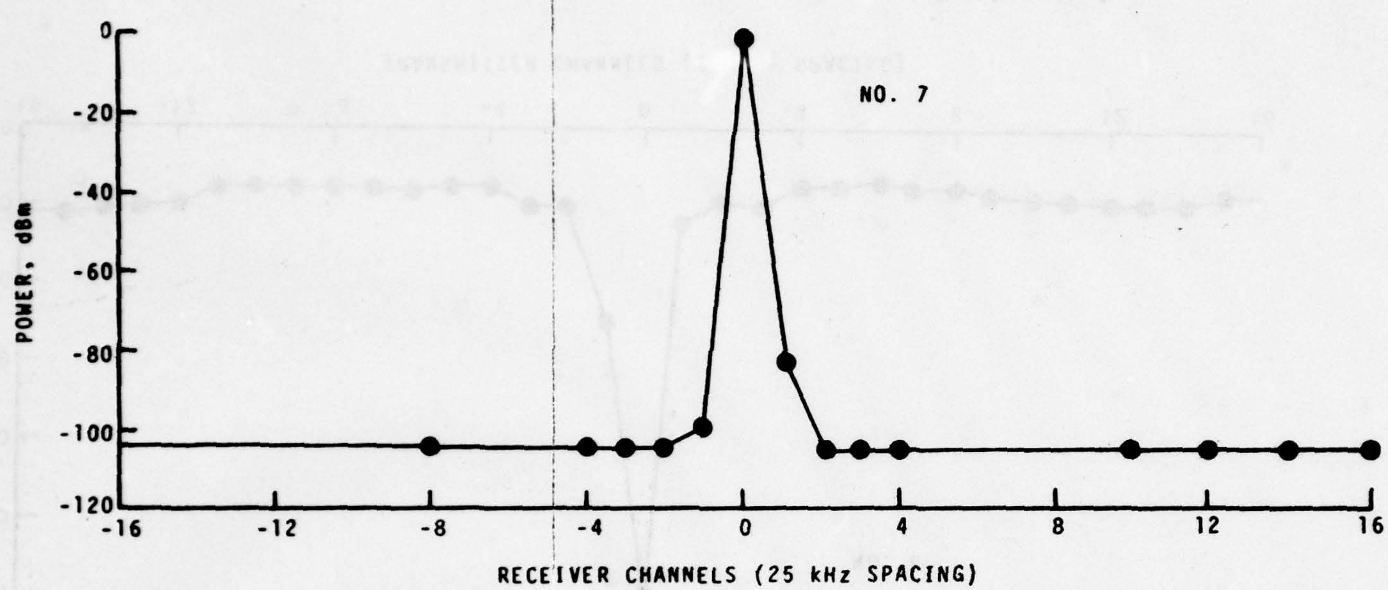


Figure 25. The TV-6 transmitter frequency fixed at 123.65 MHz versus the output of the GRR-23 receiver as it was varied plus and minus 20 channels.

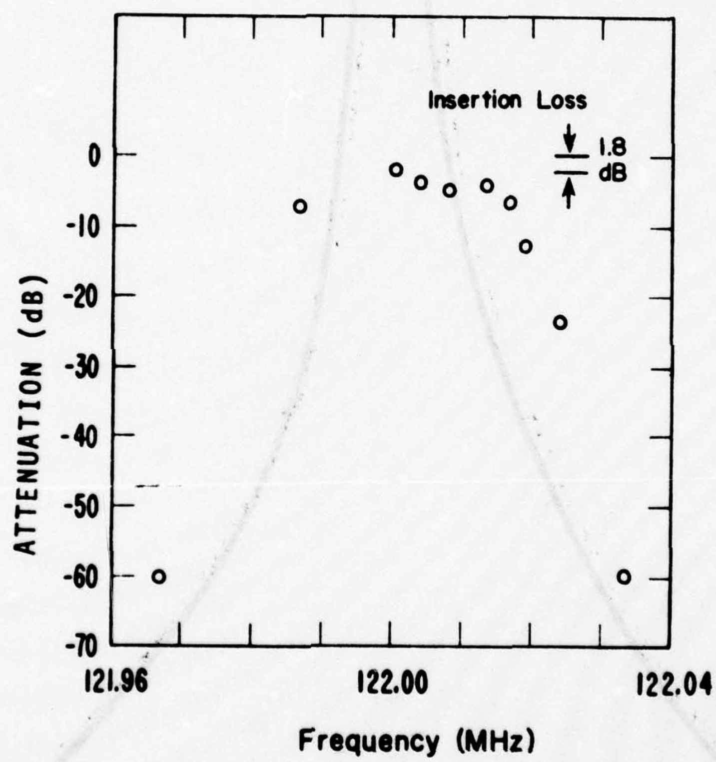


Figure 26. Characteristic of the McCoy filter.

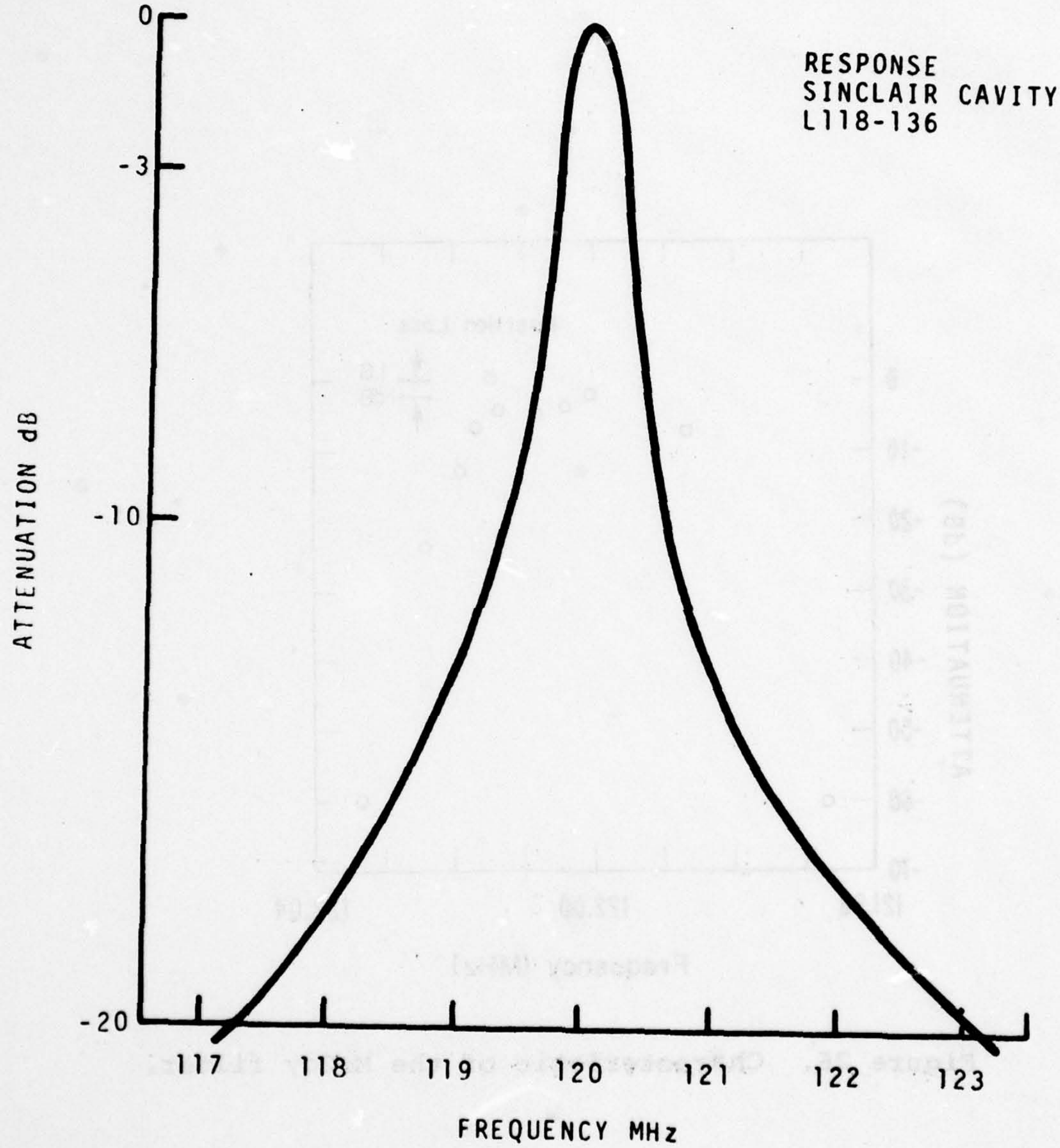


Figure 27. Characteristic of the Sinclair cavity.

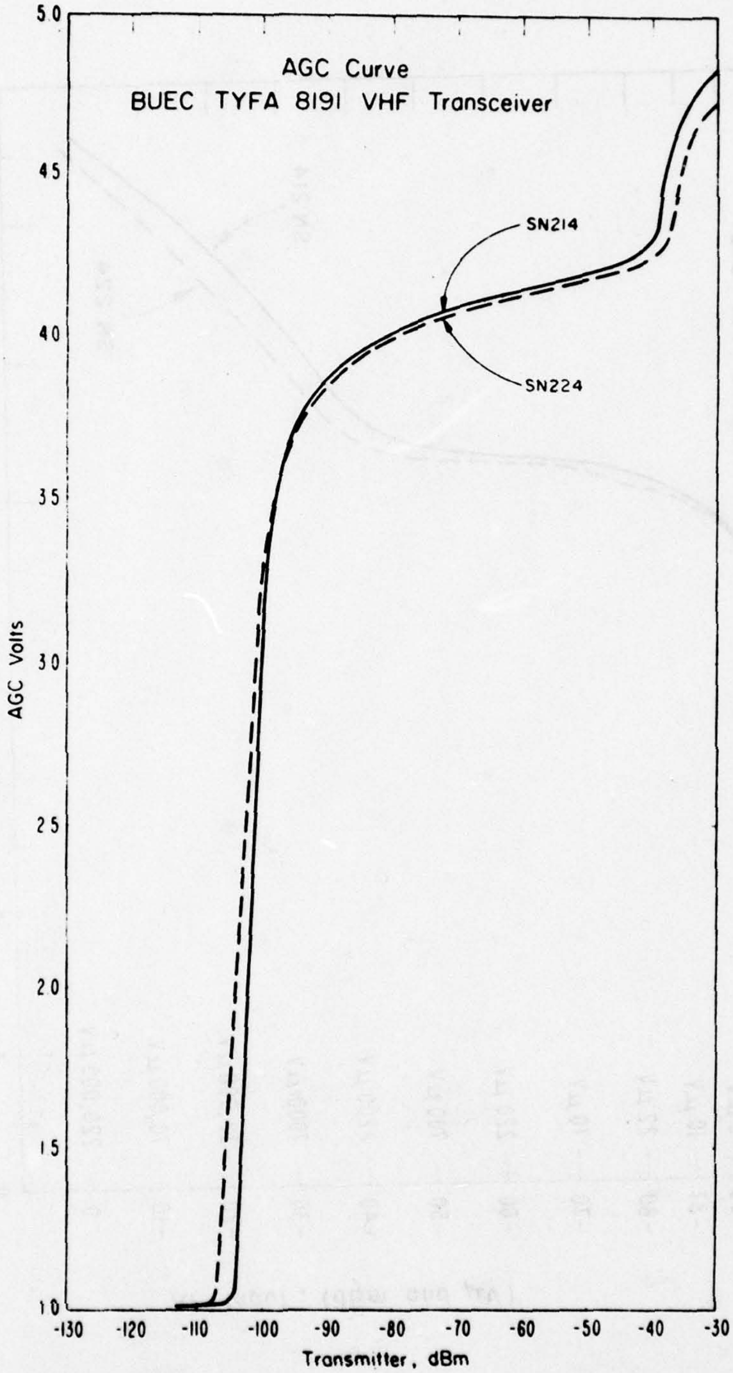


Figure 28. Transceiver calibration curves (RF signal input versus AGC output) for the BUEC FA-8191 VHF Transceiver.

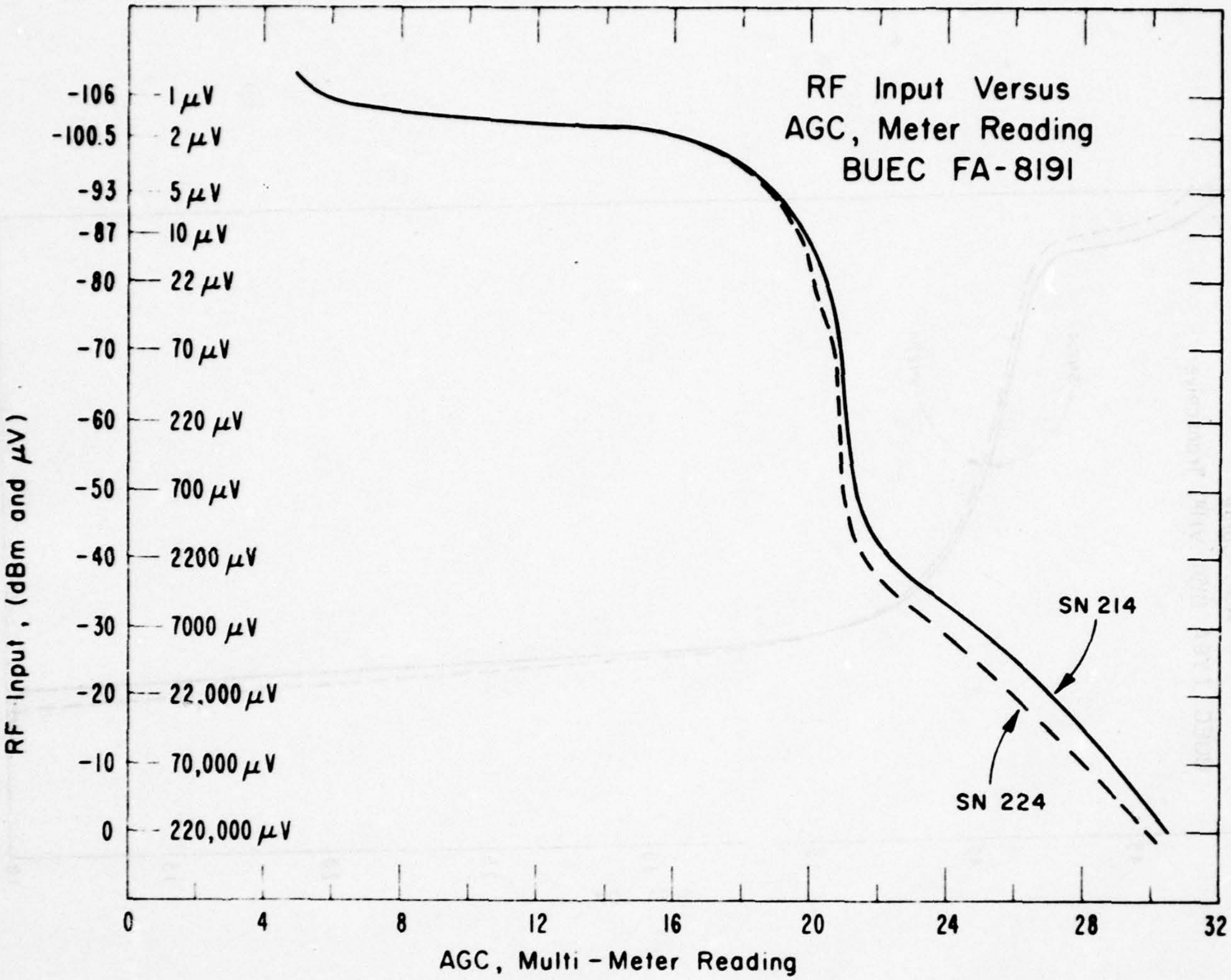


Figure 29. Calibration curves for RF input versus AGC for the BUEC FA-8191 Transceiver.

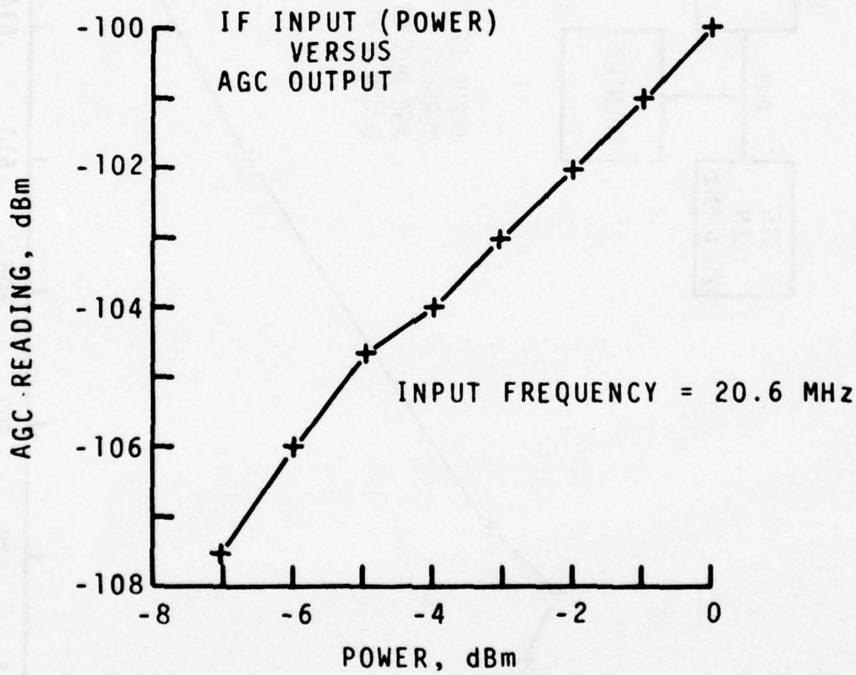


Figure 30. IF input power vs. AGC output for the BUEC-224 receiver.

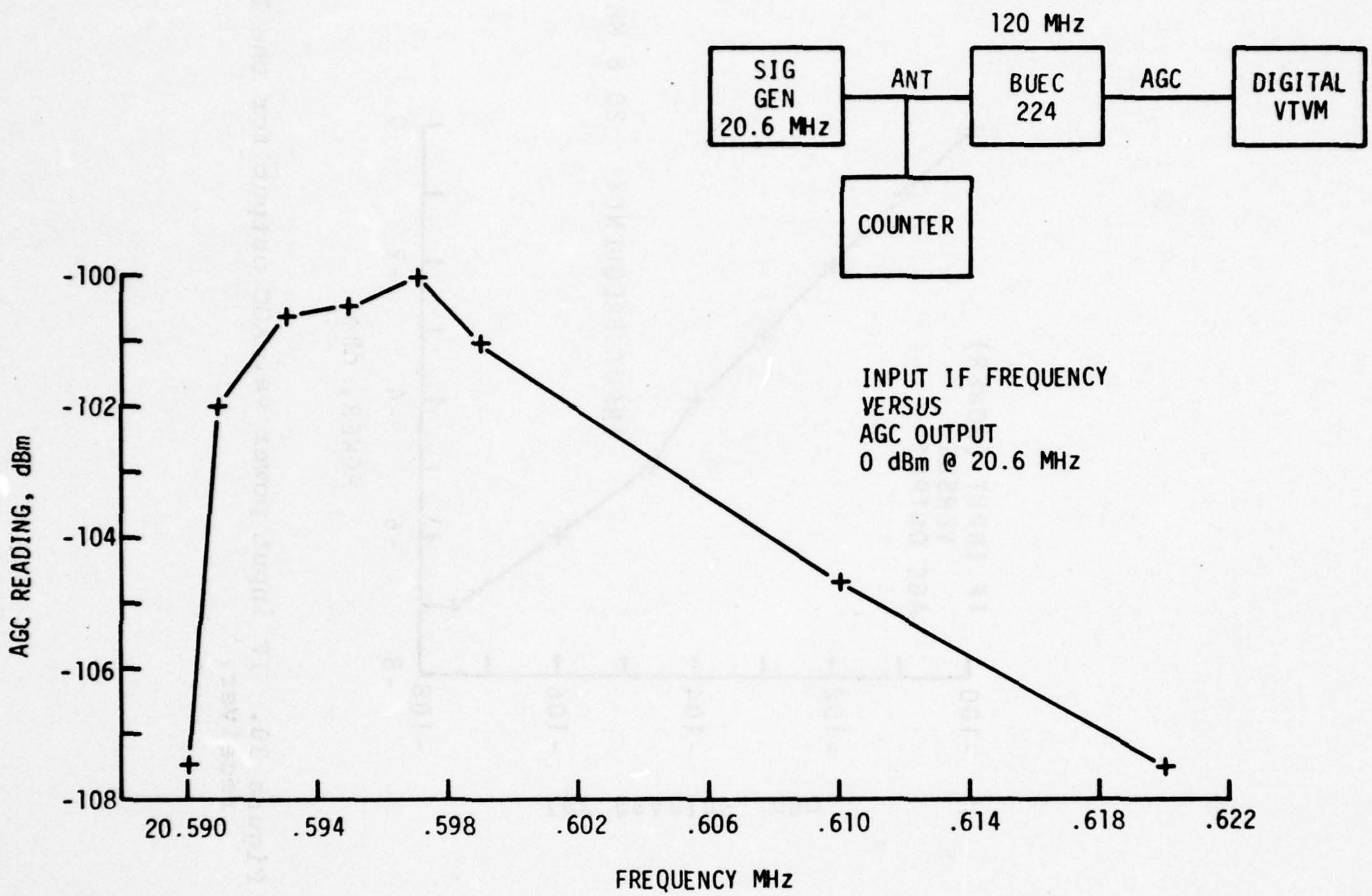


Figure 31. IF input frequency versus AGC output for 0 dBm at 20.6 MHz for the BUEC-224 receiver.

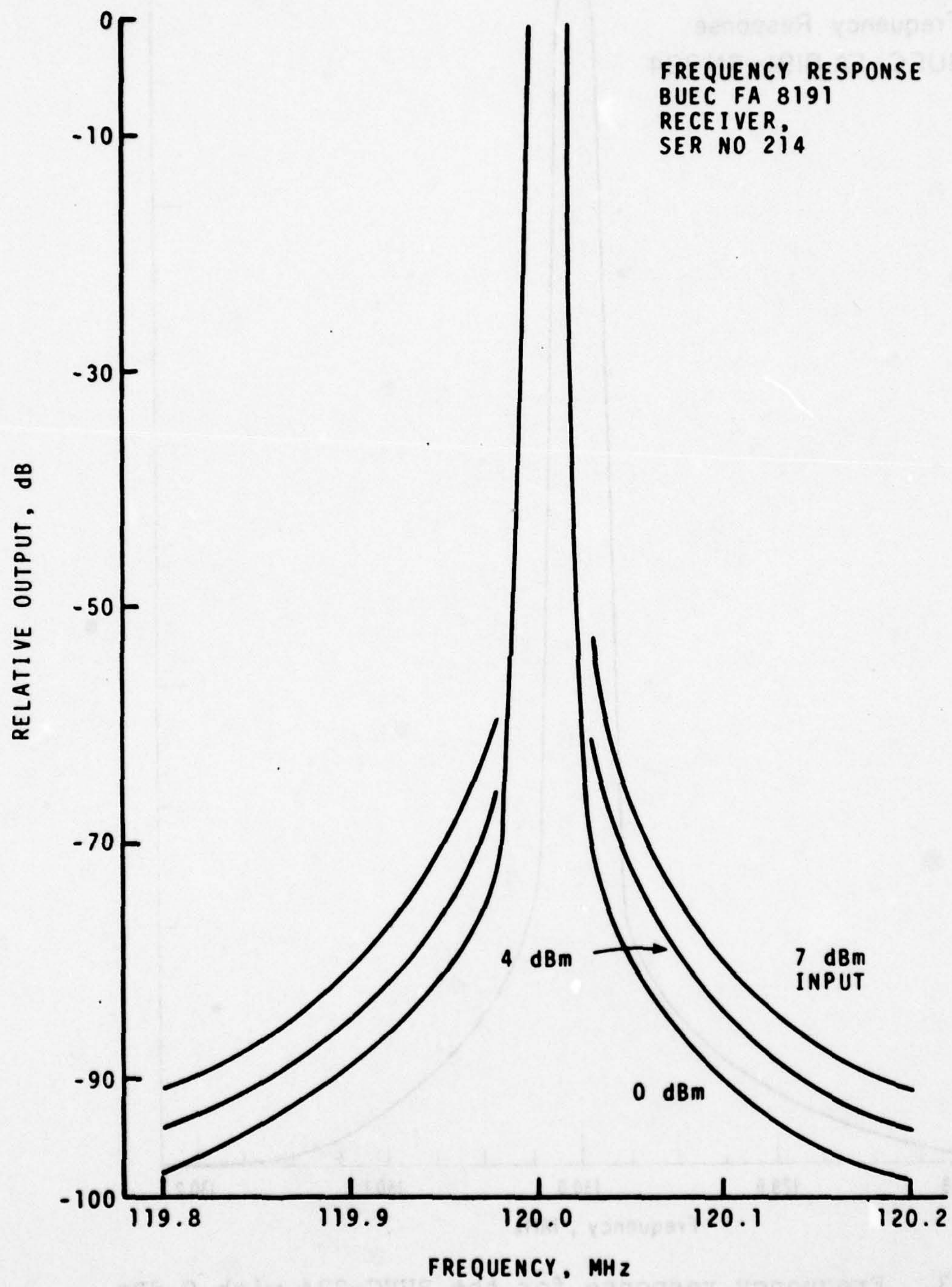


Figure 32. Frequency response for the BUEC FA-8191 Receiver with + 7 dBm input.

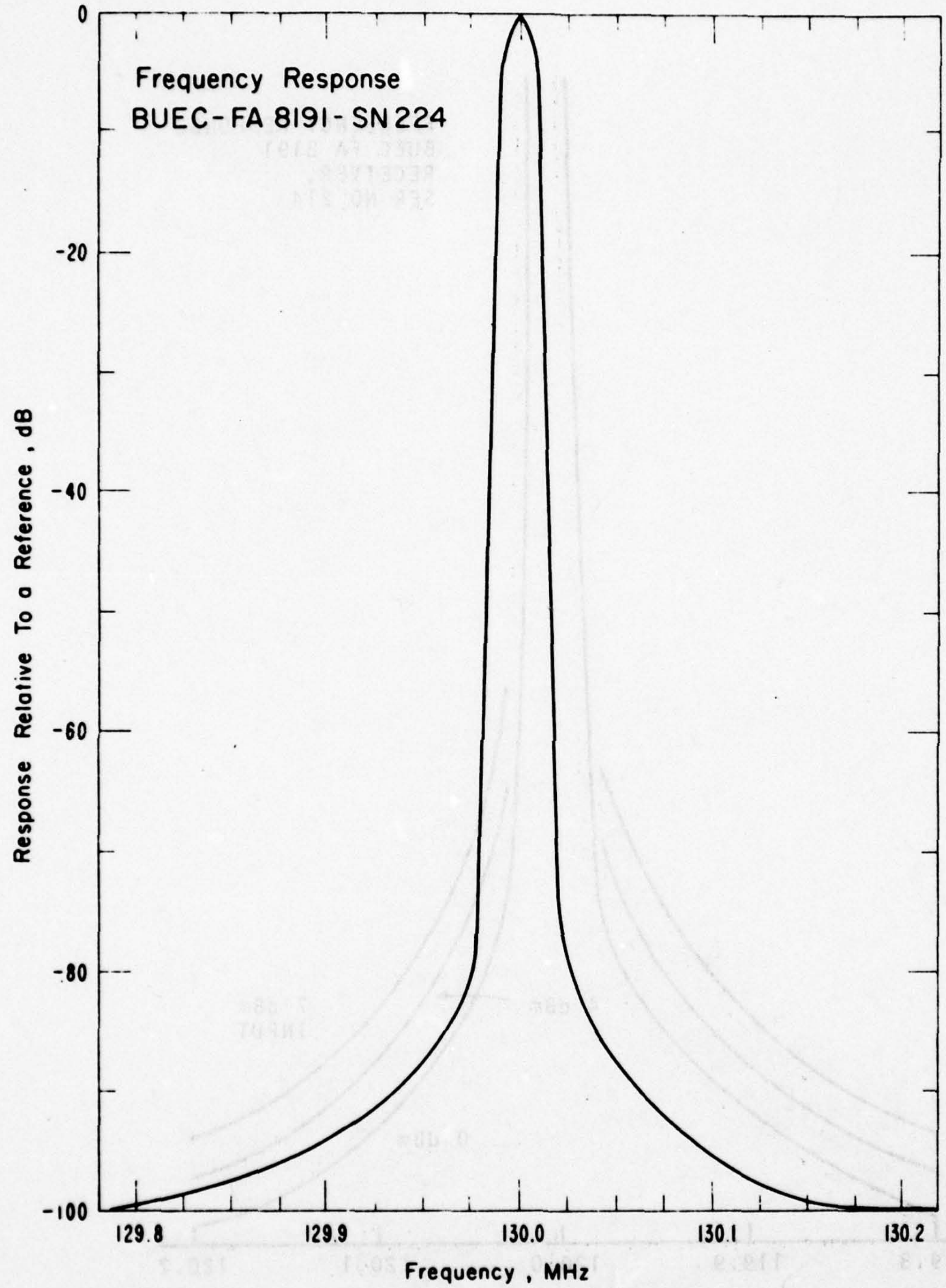


Figure 33. Frequency response for the BUEC-224 with 0 dBm input.

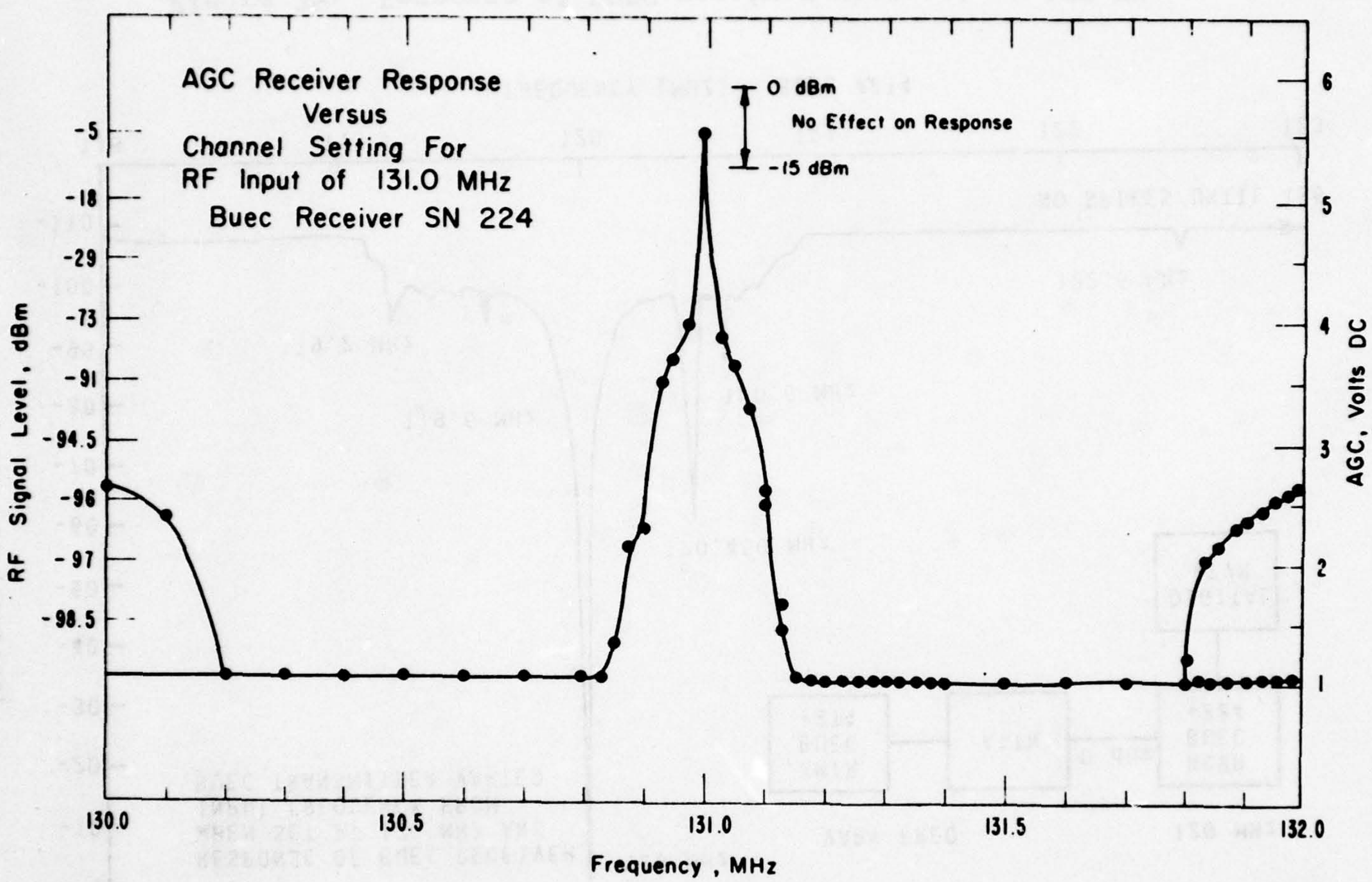


Figure 34. AGC receiver response versus channel setting for rf input at 131.0 MHz. (BUEC-224)

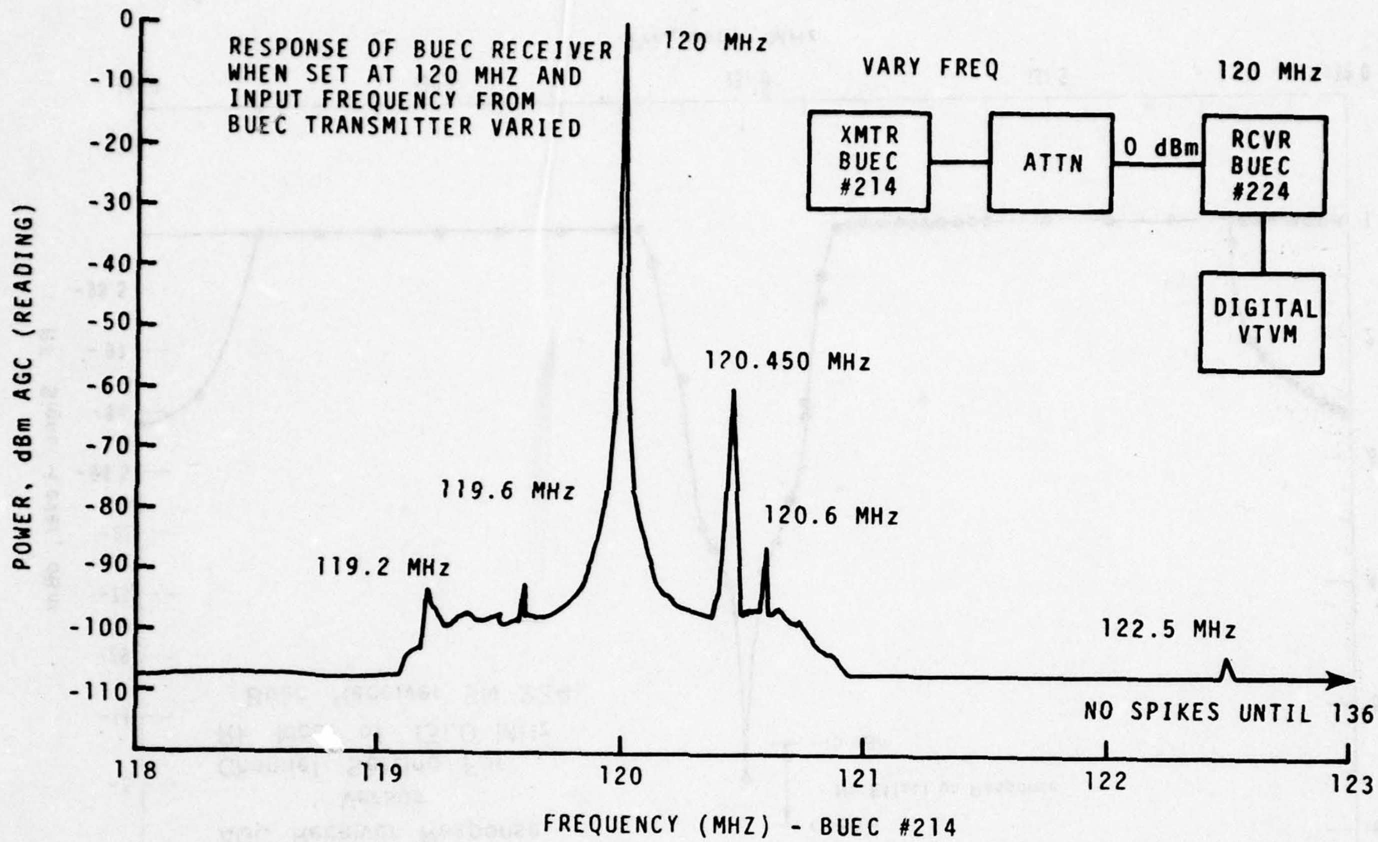


Figure 35. Response of BUEC receiver when set at 120 MHz and input frequency from BUEC transmitter varied.

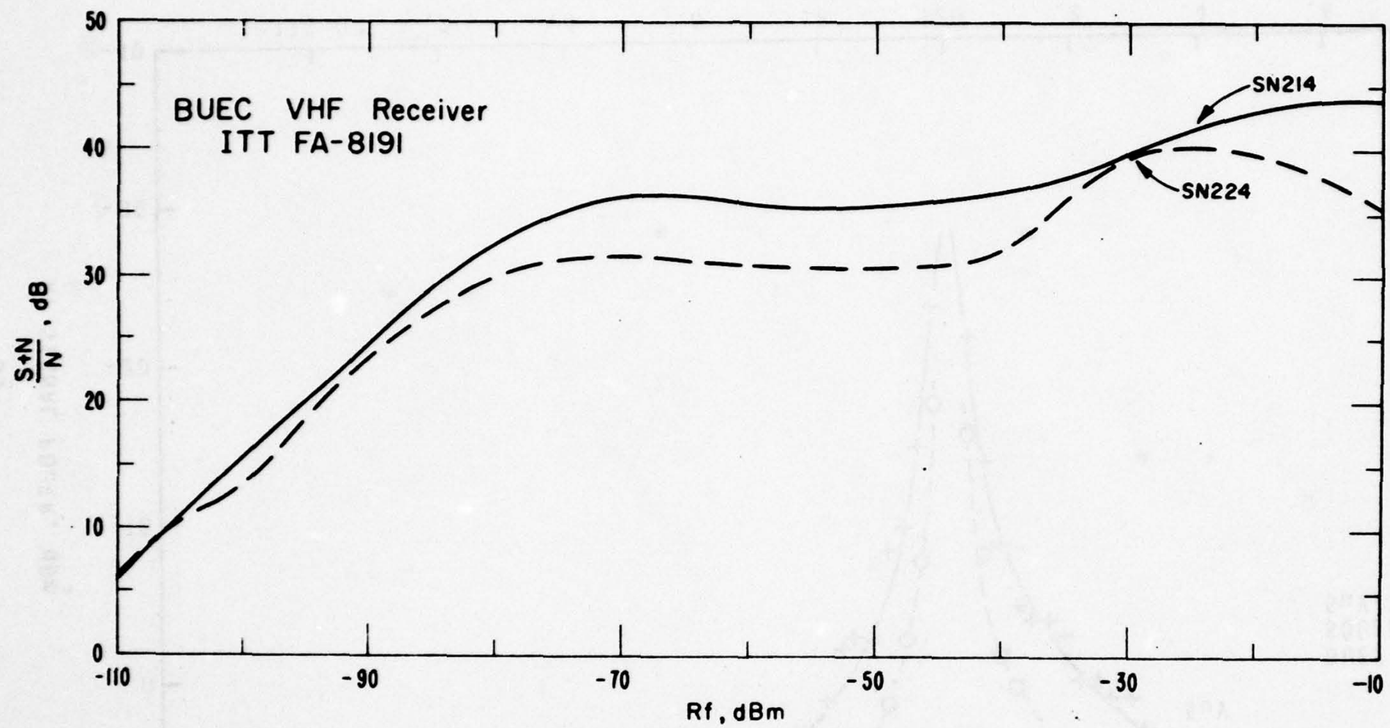


Figure 36. Signal-plus-noise to noise ratios for the two BUEC receivers as a function of input power.

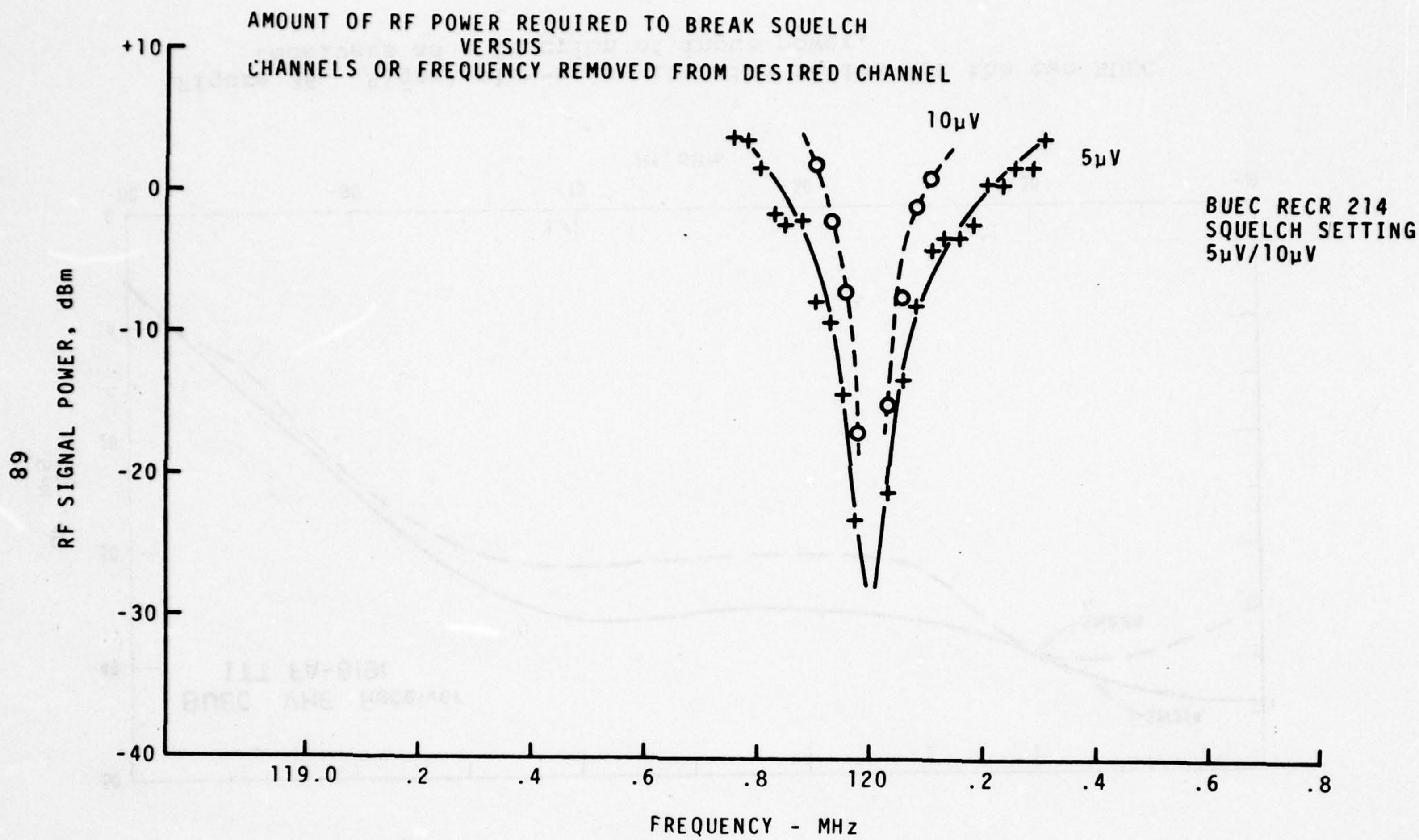


Figure 37. Amount of rf power required to break squelch as a function of channel separation or frequency removed from desired channel. (BUEC-214)

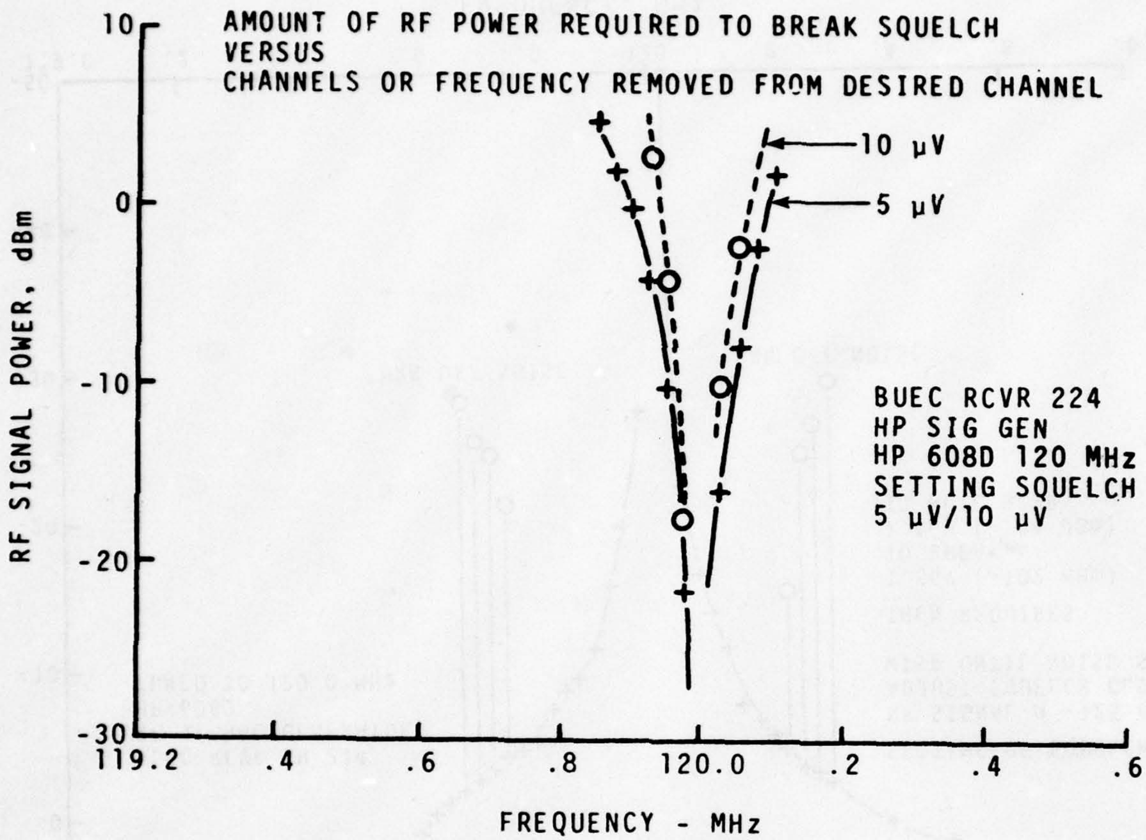


Figure 38. Amount of rf power required to break squelch as a function of channel separation or frequency removed from desired channel. (BUEC-224)

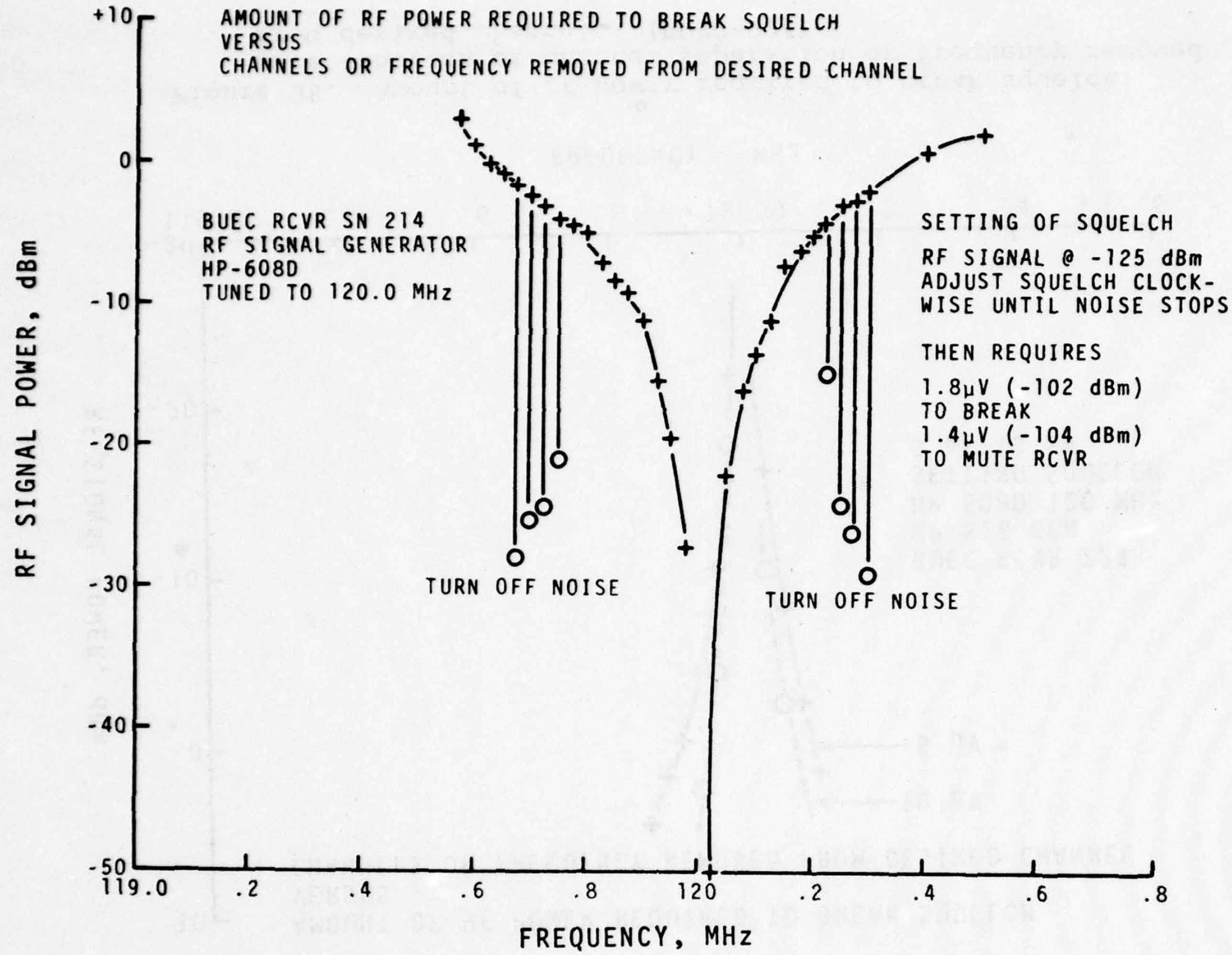


Figure 39. Amount of rf power required to break squelch versus channels or frequency removed from desired channel. (BUEC-224)

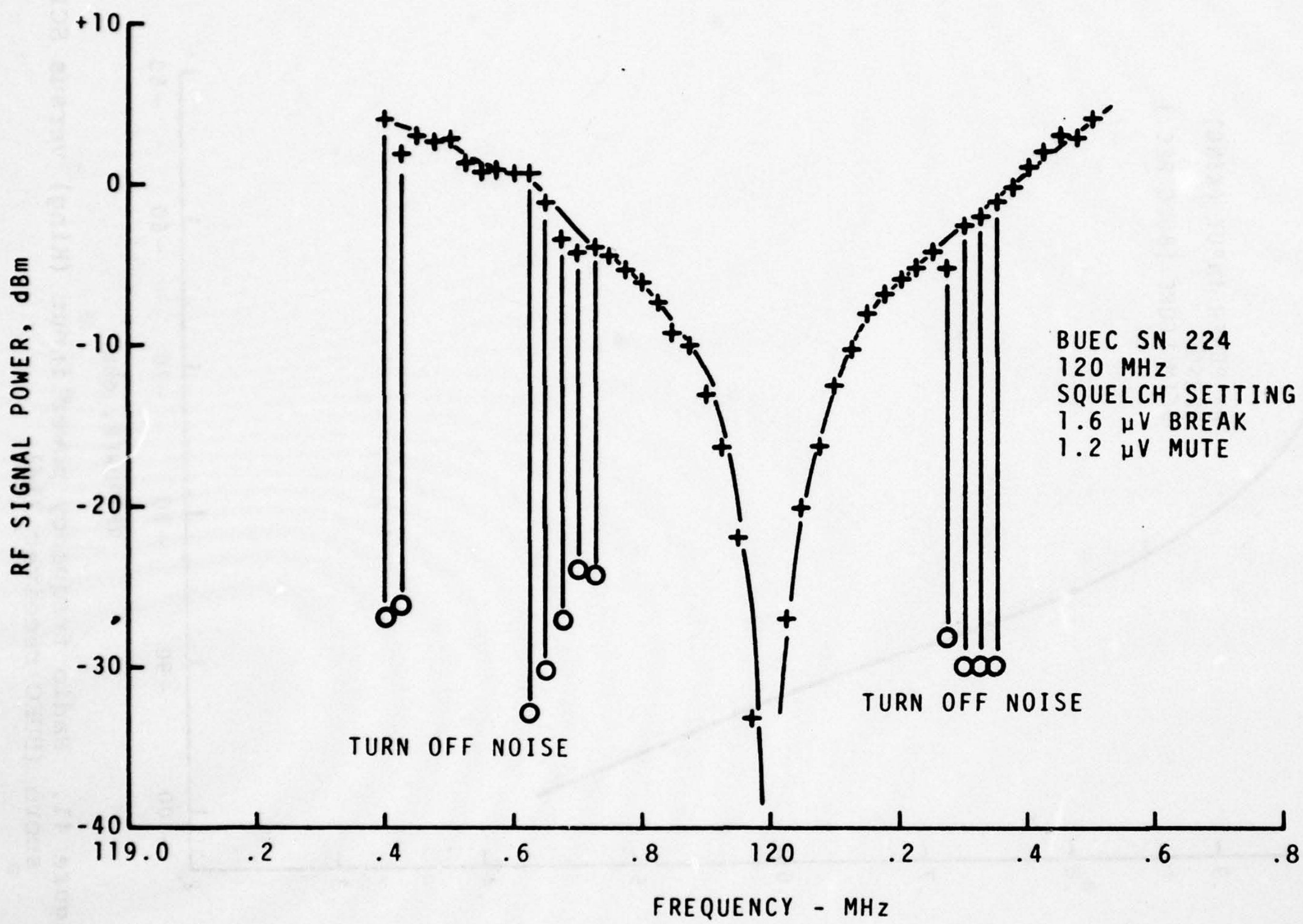


Figure 40. Amount of rf power required to break squelch versus channels or frequency removed from desired channel. (BUEC-224)

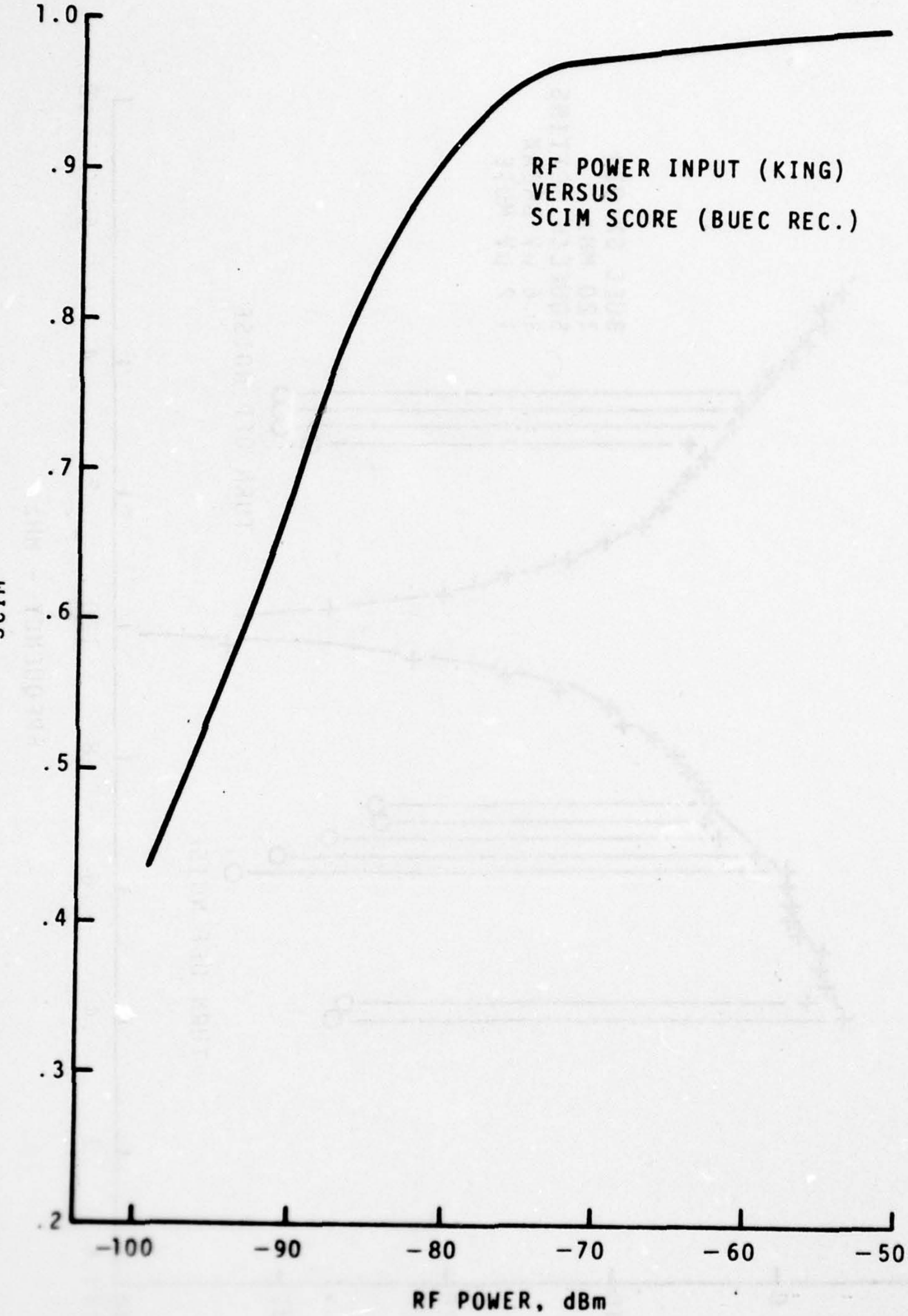


Figure 41. Radio frequency power input (King) versus SCIM score (BUEC receiver 214).

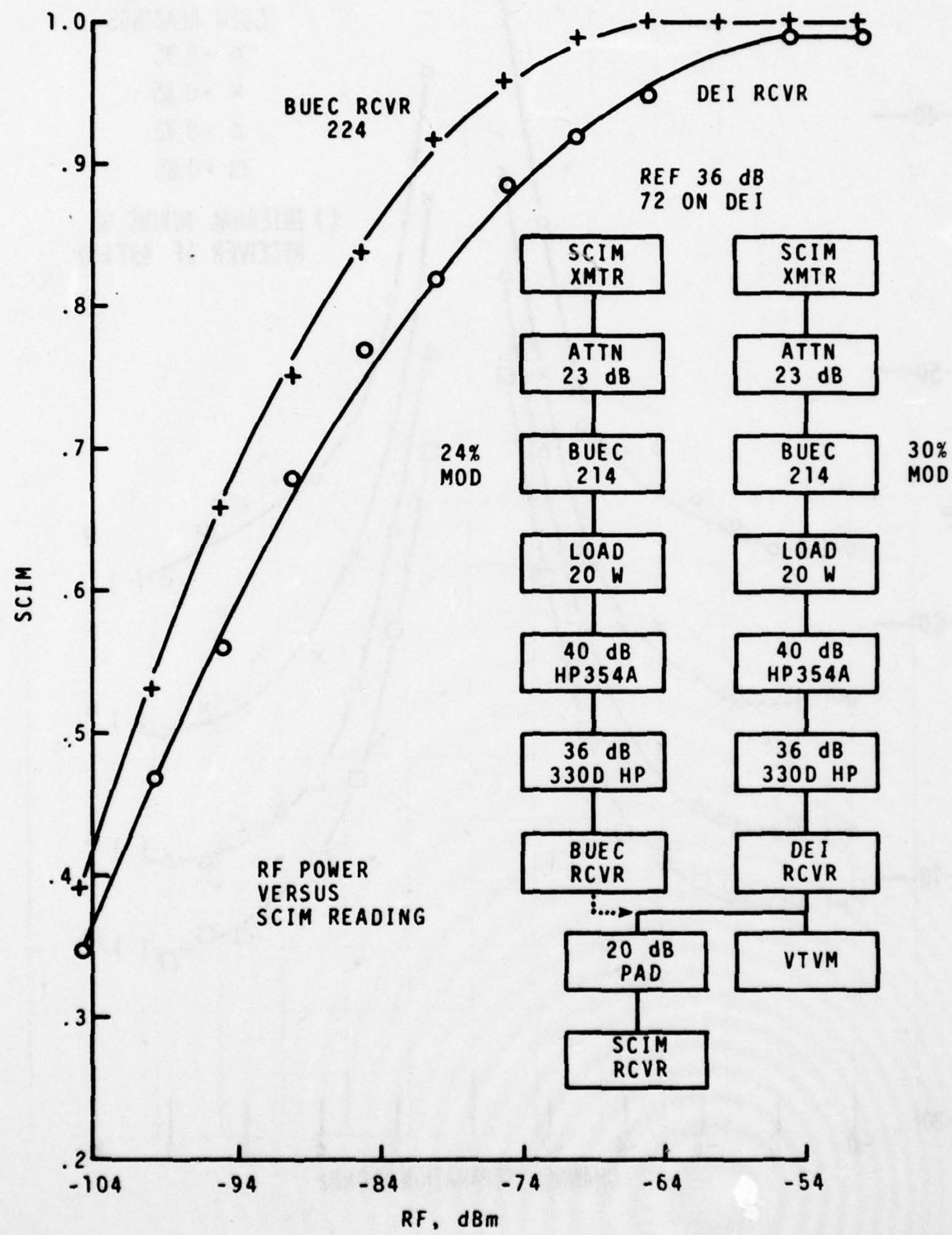


Figure 42. Radio frequency power versus SCIM reading for the BUEC-224 and DEI receivers.

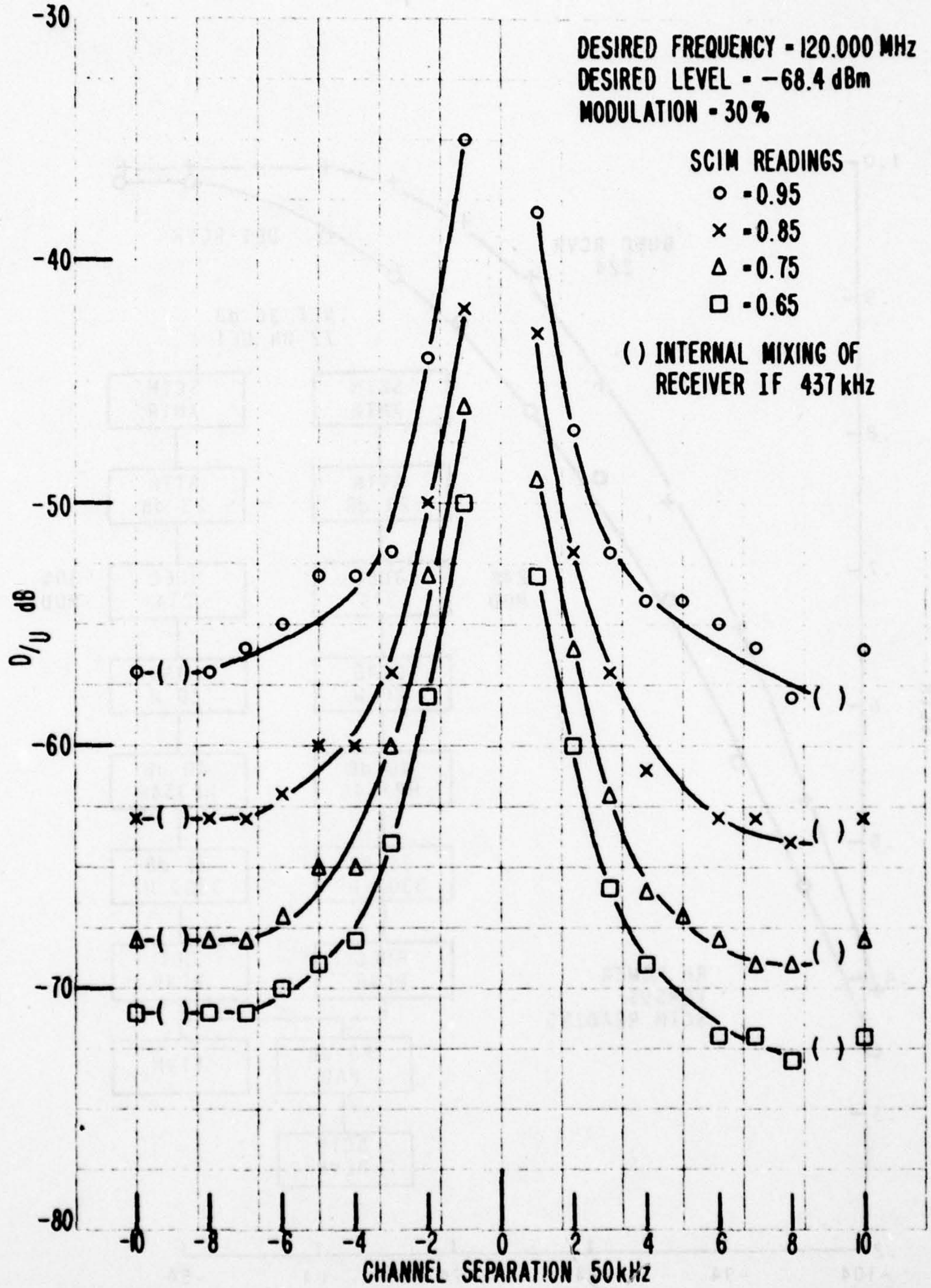


Figure 43. A family of curves reflecting the desired to undesired (D/U) rf ratio versus SCIM readings for the BUEC receiver, 50 kHz channel. (BUEC-224)

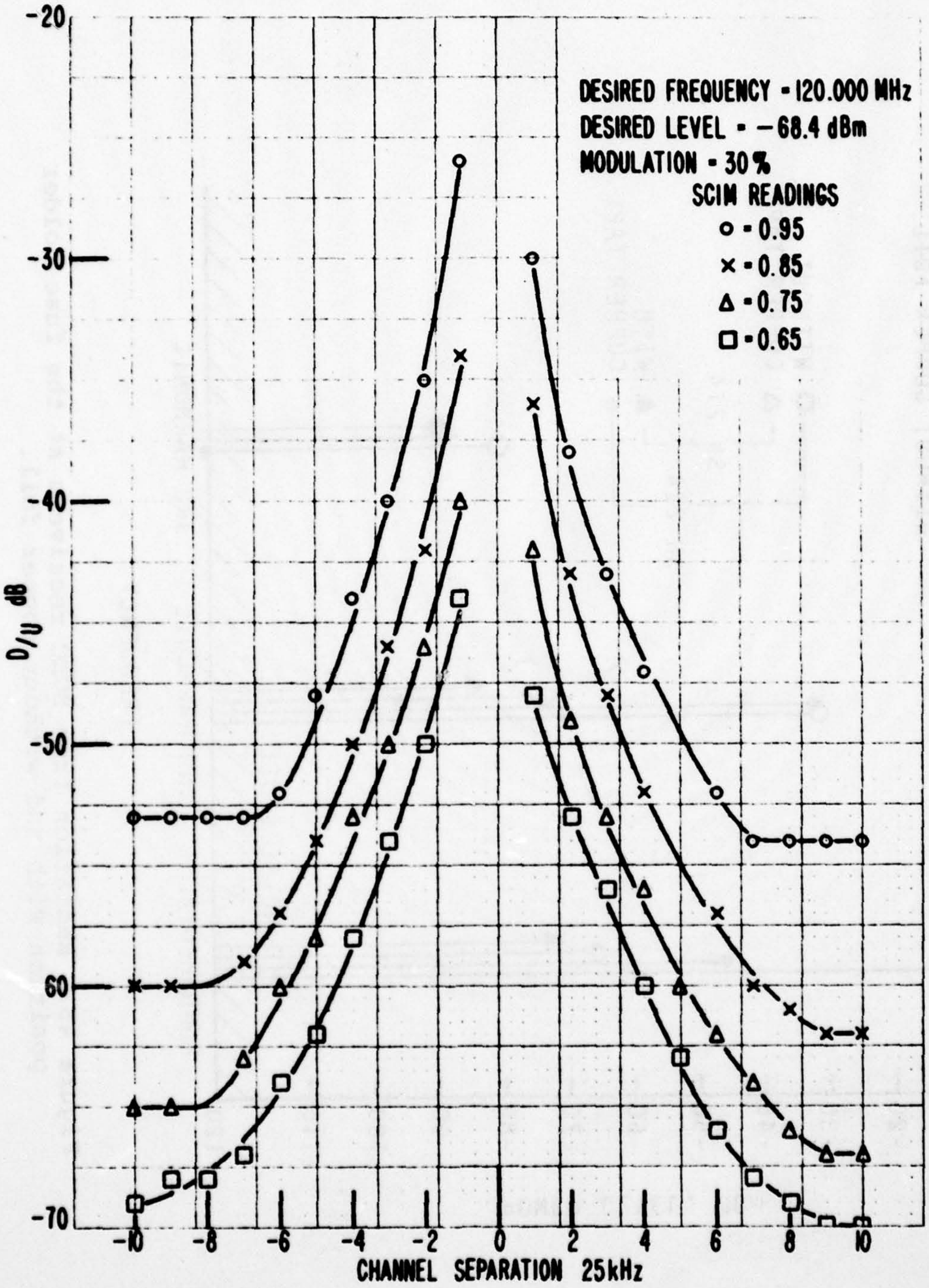


Figure 44. A family of curves reflecting the desired to undesired (D/U) rf ratio versus SCIM readings for 25 kHz channel spacings. (BUEC-224)

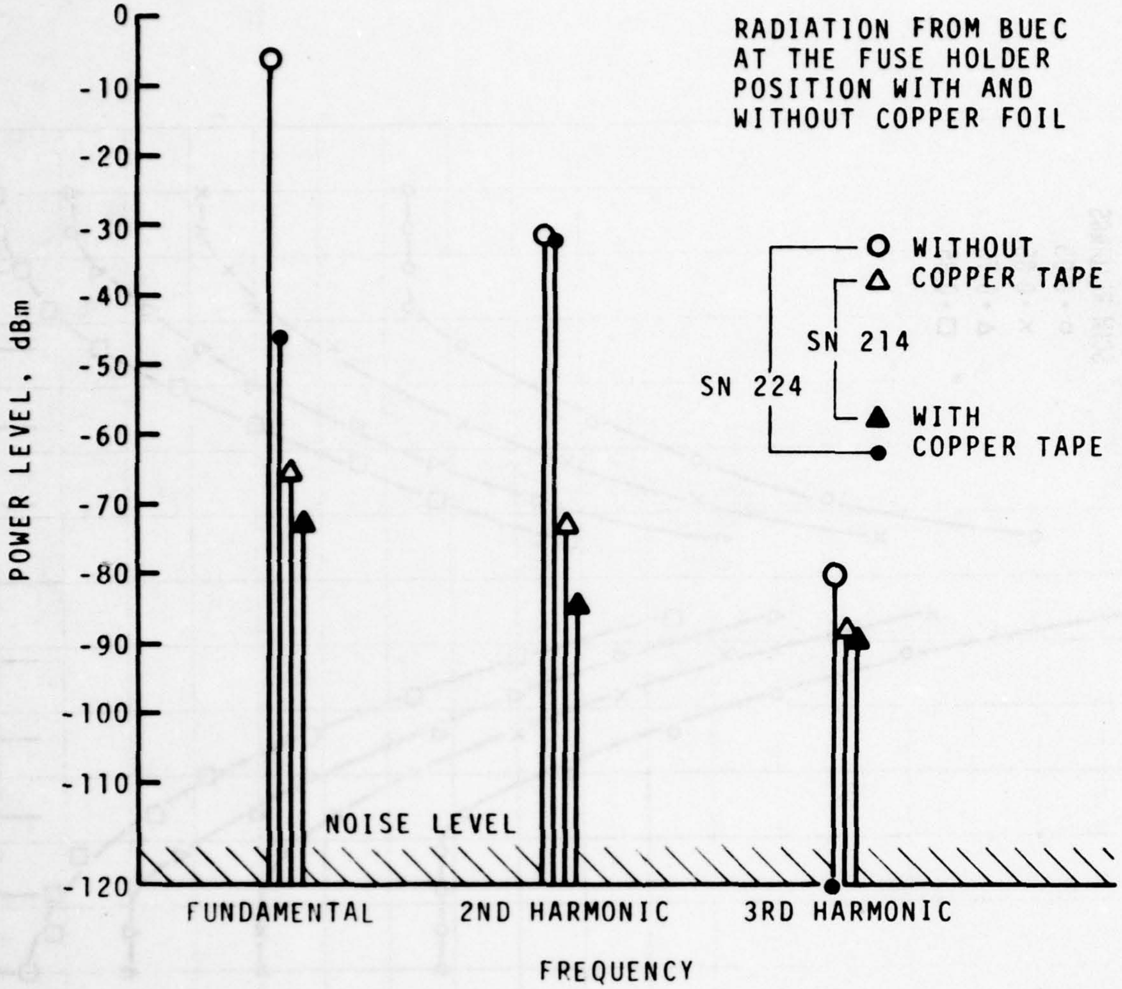


Figure 45. Radiation from BUEC receivers at the fuse holder position with and without copper foil.

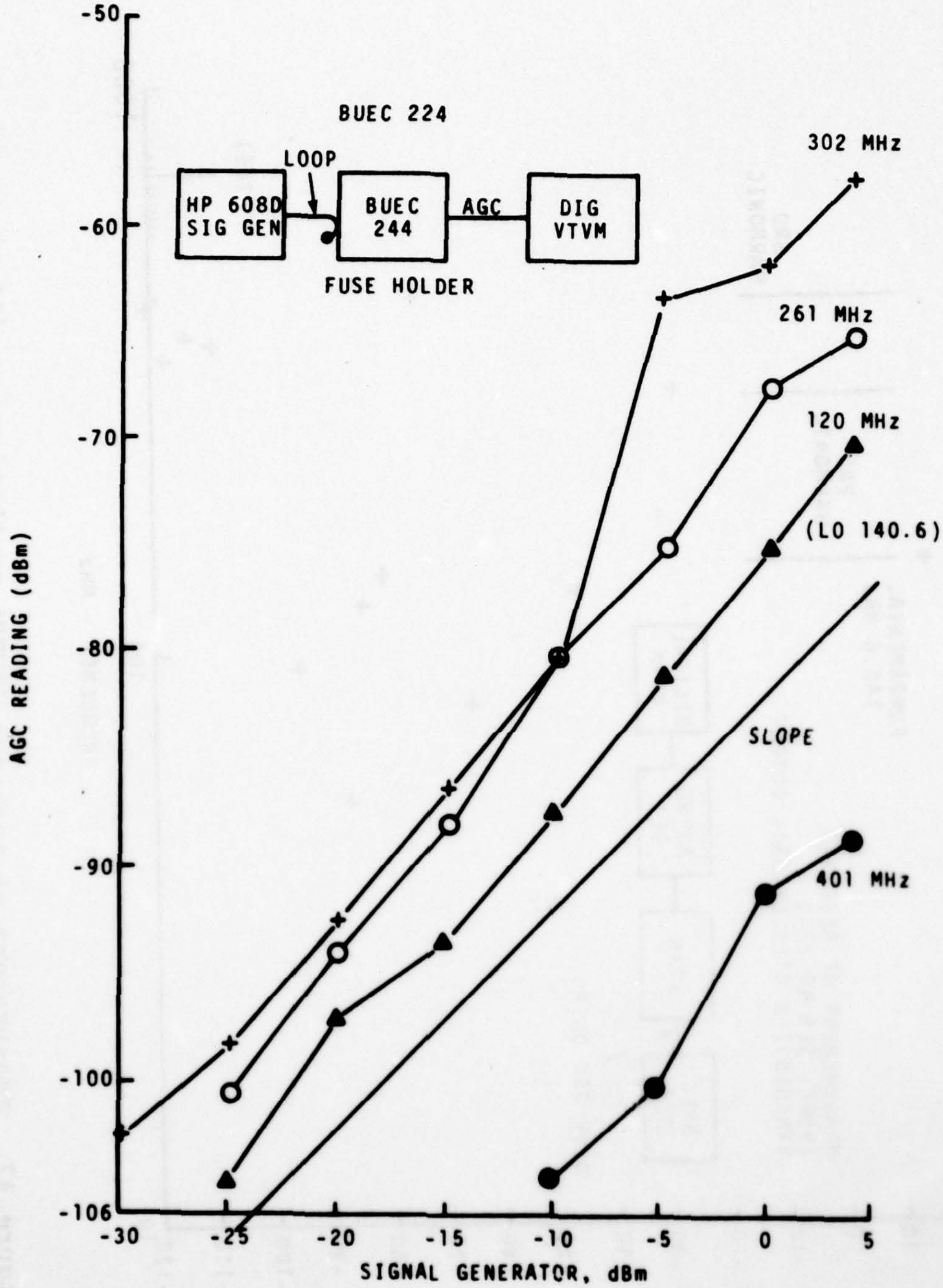


Figure 46. Radio frequency leakage through the fuse holders of the BUEC receivers at 120, 261, 302 and 401 MHz.

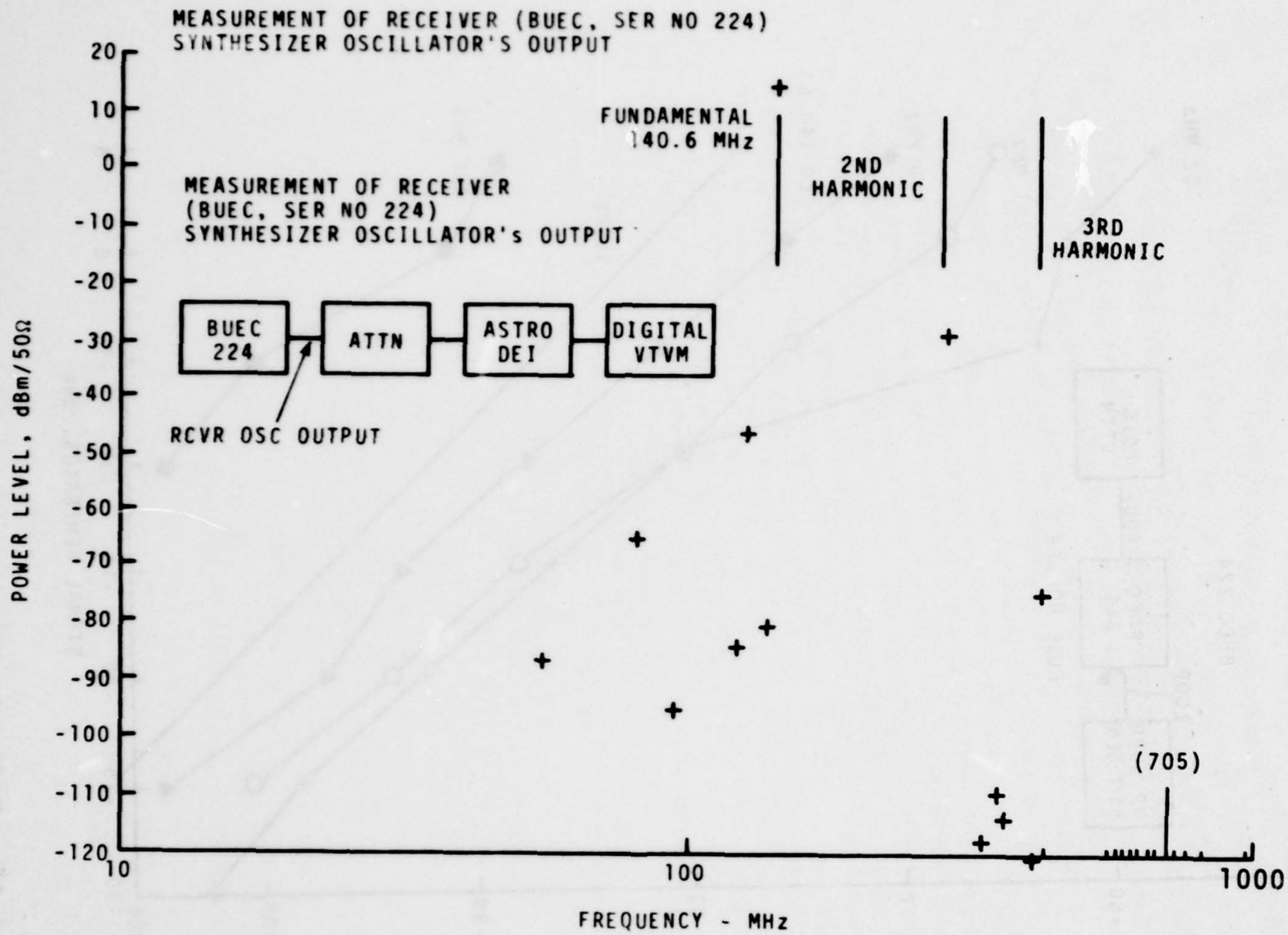


Figure 47. Measurement of receiver (BUEC) synthesizer oscillator's output.

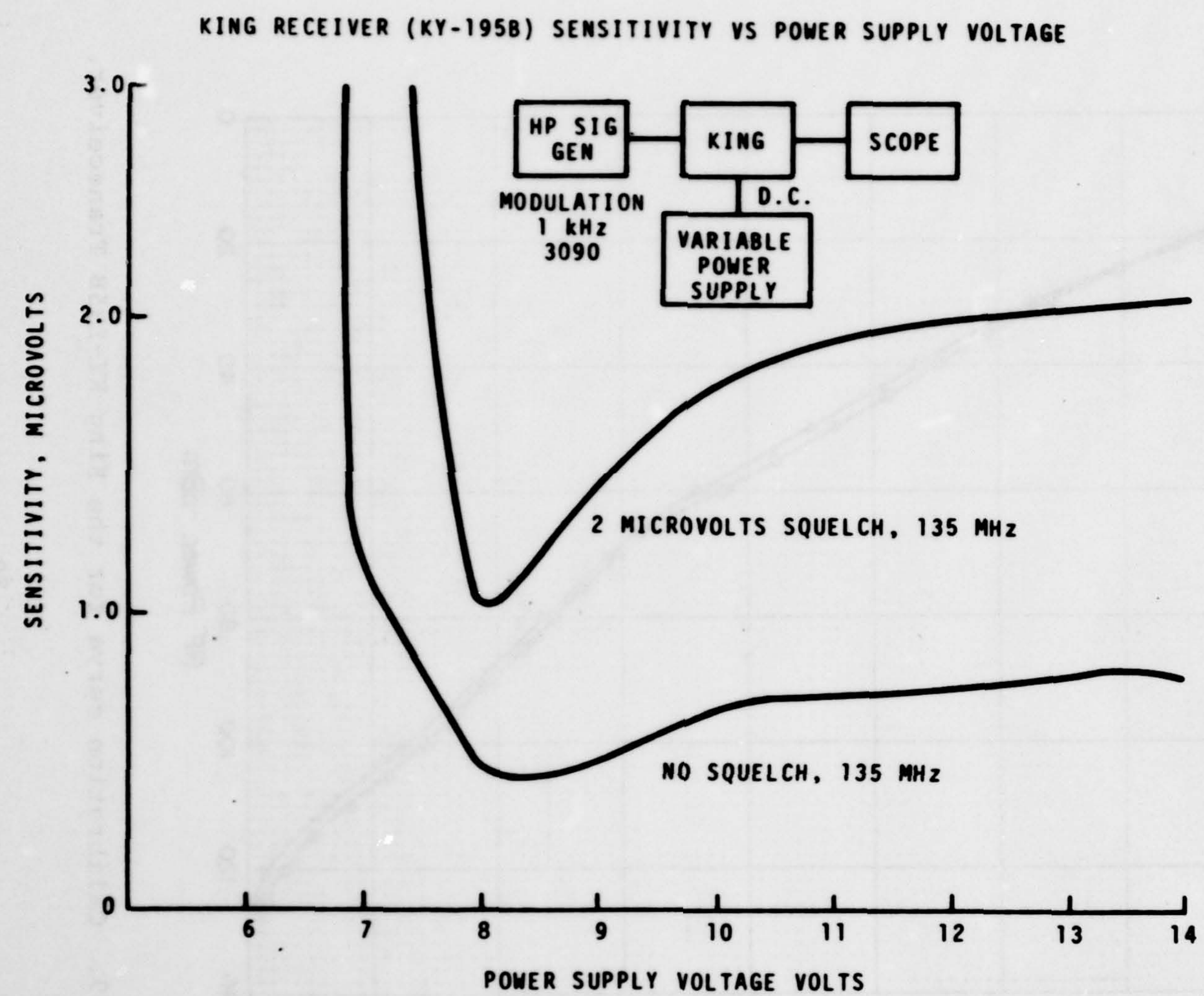


Figure 48. King receiver (KY-195B) sensitivity versus power supply voltage.

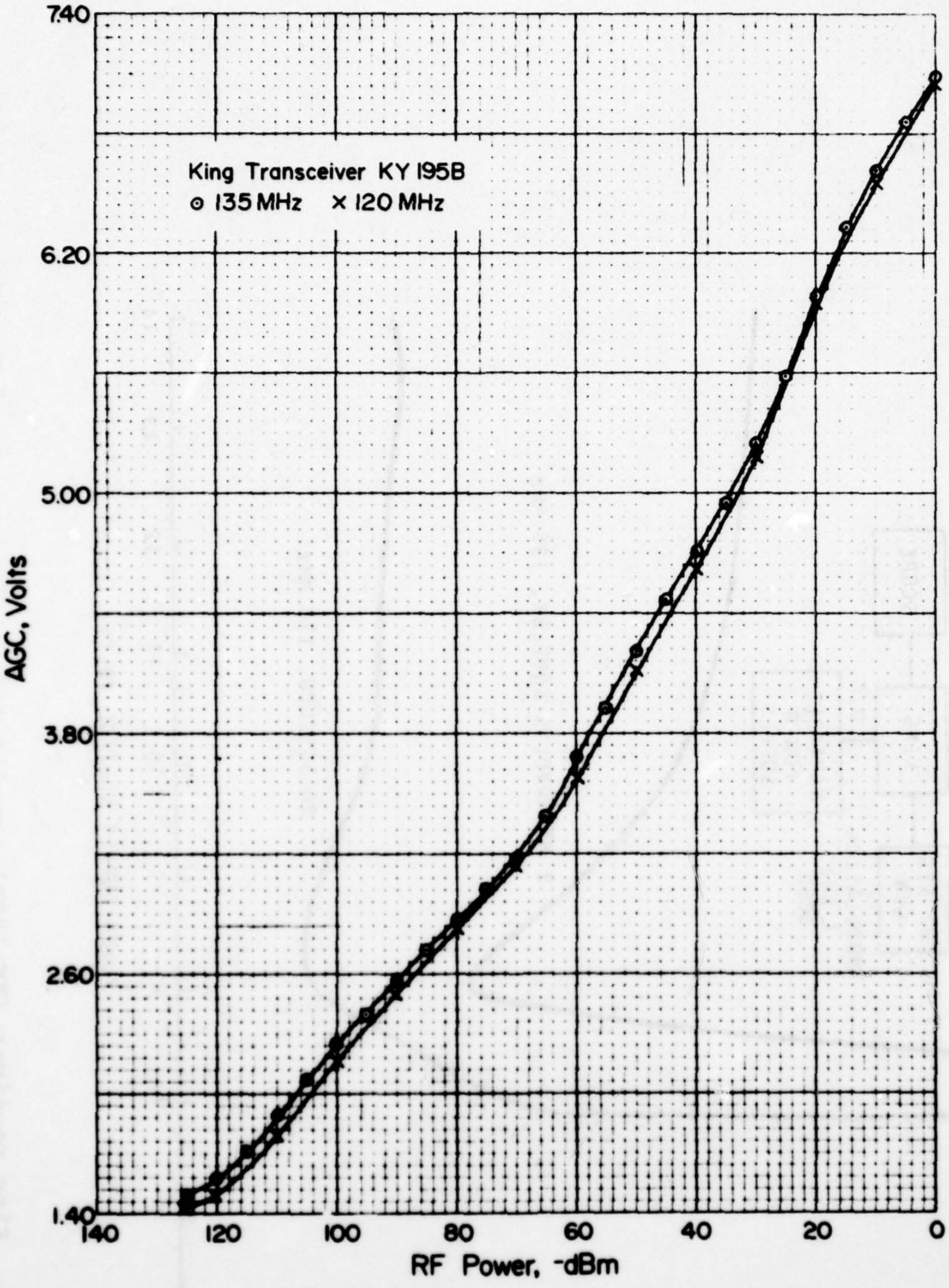


Figure 49. Calibration curve for the King KY-195B Transceiver.

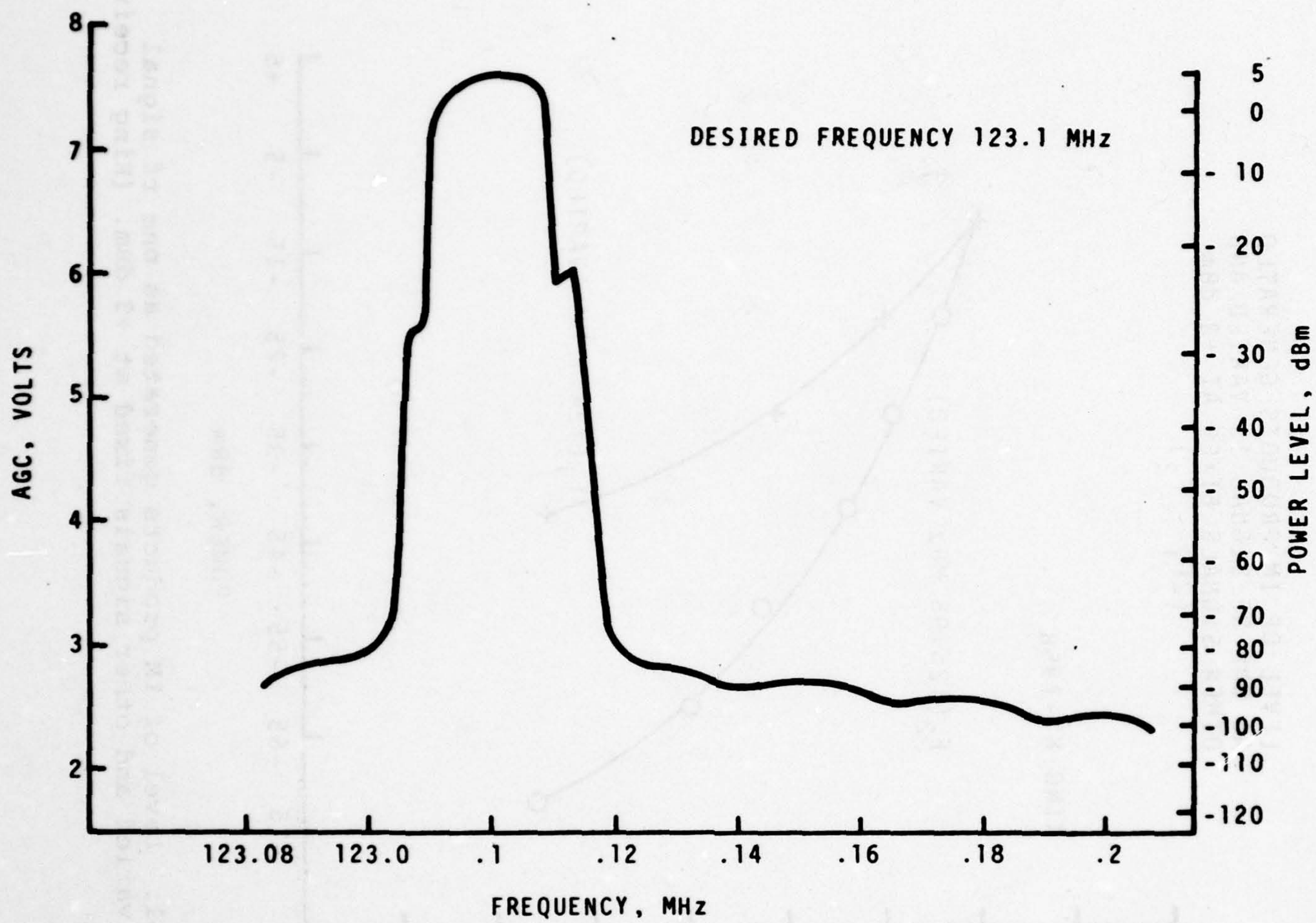


Figure 50. Response of the King KY-195B receiver.

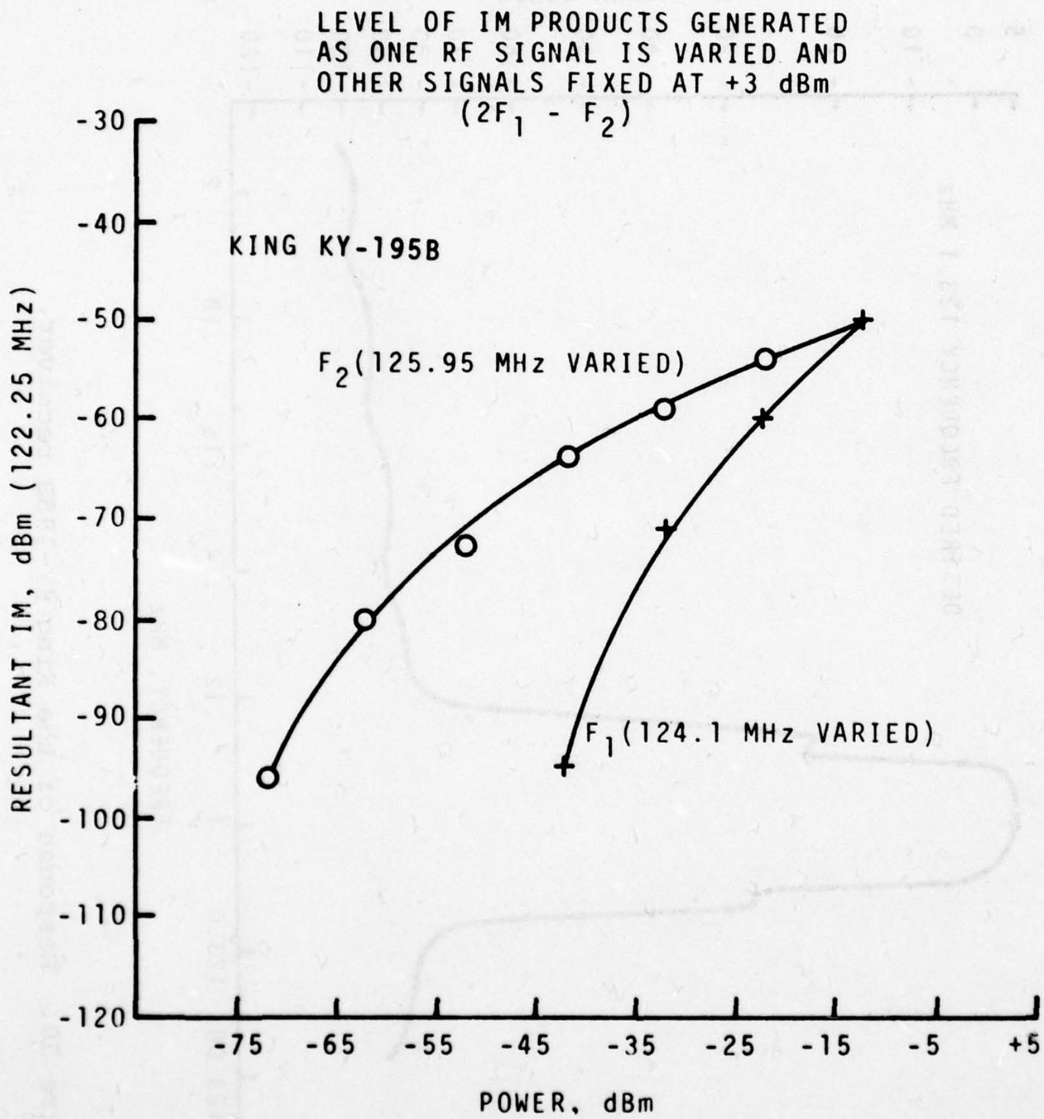


Figure 51. Level of IM products generated as one rf signal is varied and other signals fixed at +3 dBm. (King receiver)

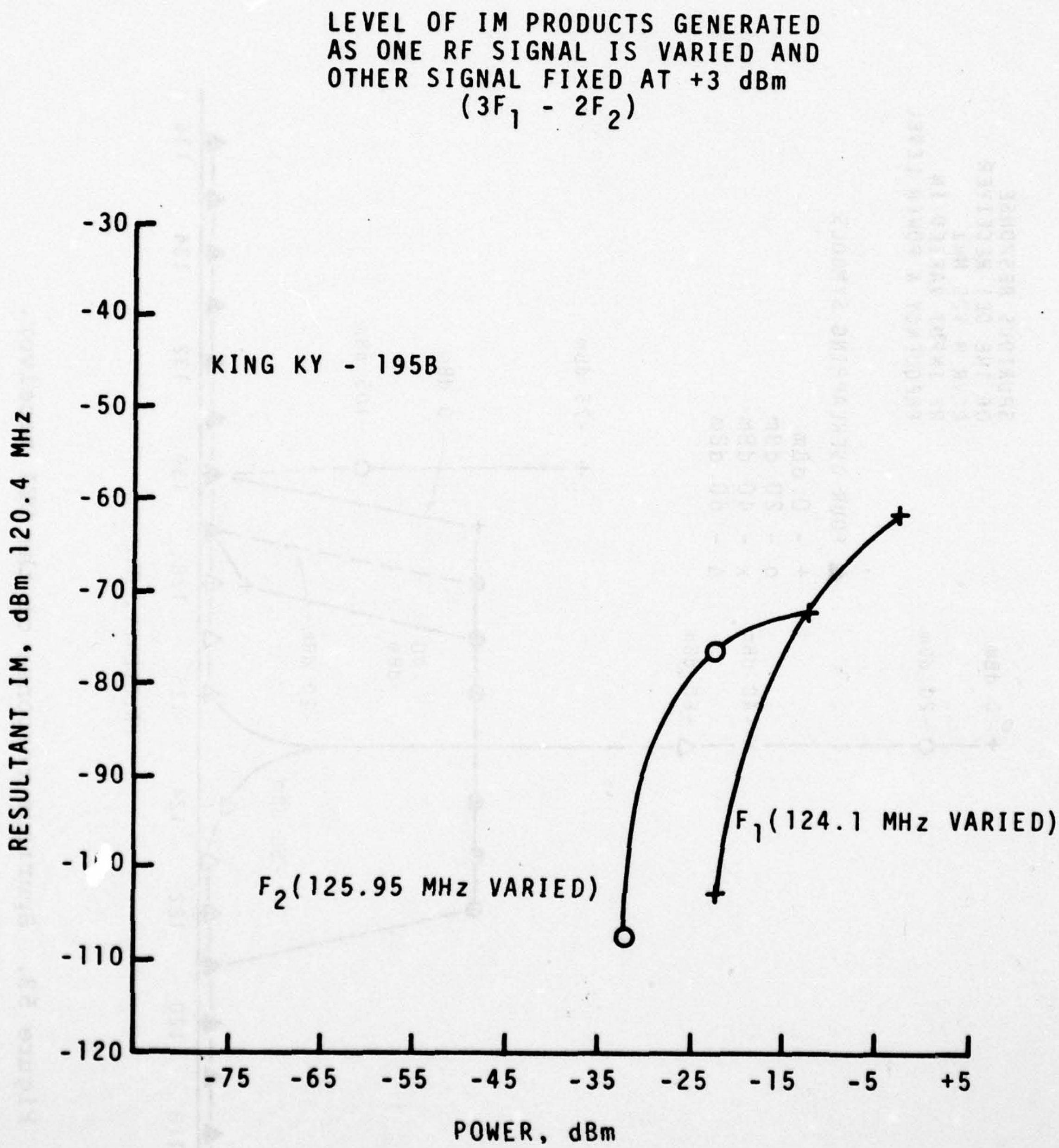


Figure 52. Level of IM products generated as one rf signal is varied and other signal fixed at +3 dBm. (King receiver)

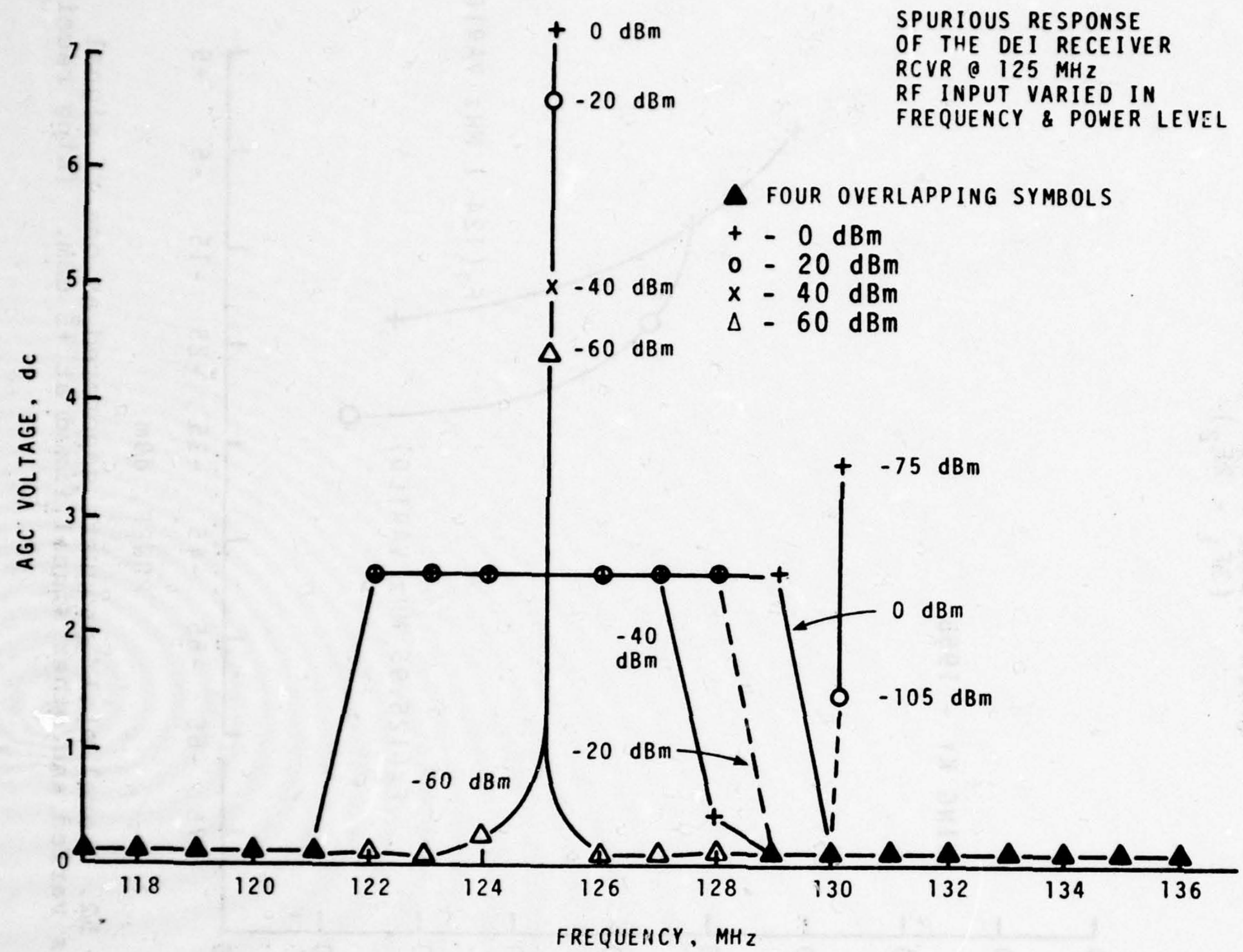


Figure 53. Spurious response of the DEI receiver.

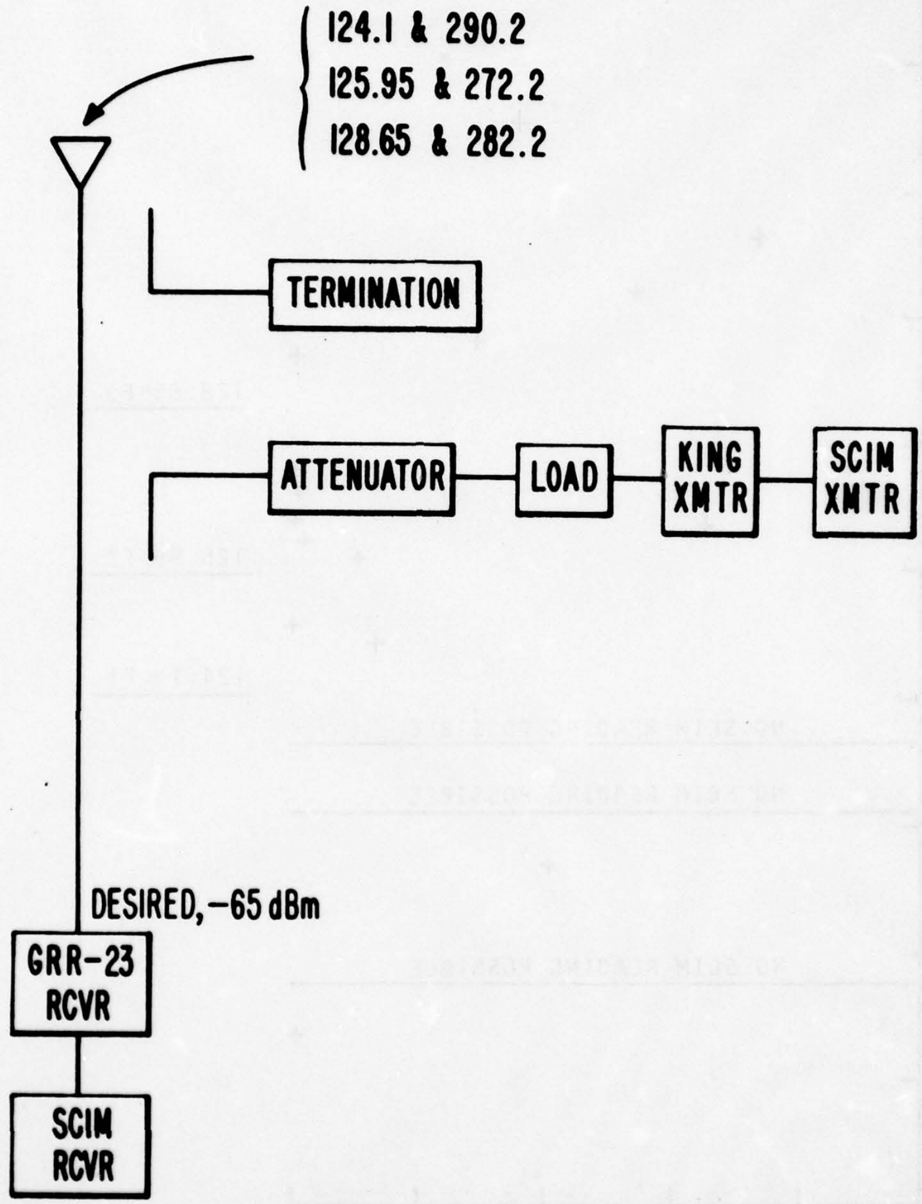


Figure 54. Equipment configuration for SCIM readings.

AD-A059 729 OFFICE OF TELECOMMUNICATIONS BOULDER COLO INST FOR TE--ETC F/G 17/7
EXAMINATION AND PREDICTION OF PROBLEMS ASSOCIATED WITH COLLOCAT--ETC(U)
DEC 75 W J HARTMAN, J J TARY DOT-FA74WAI-447

UNCLASSIFIED FAA-RD-75-157 NL

2 OF 2
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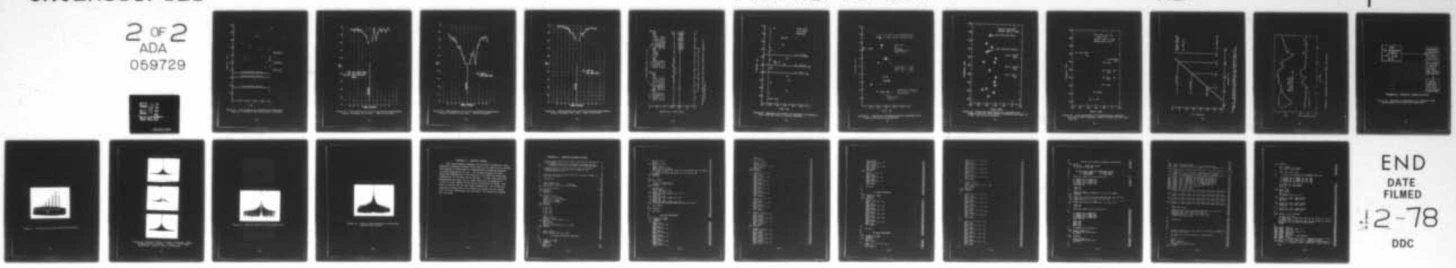

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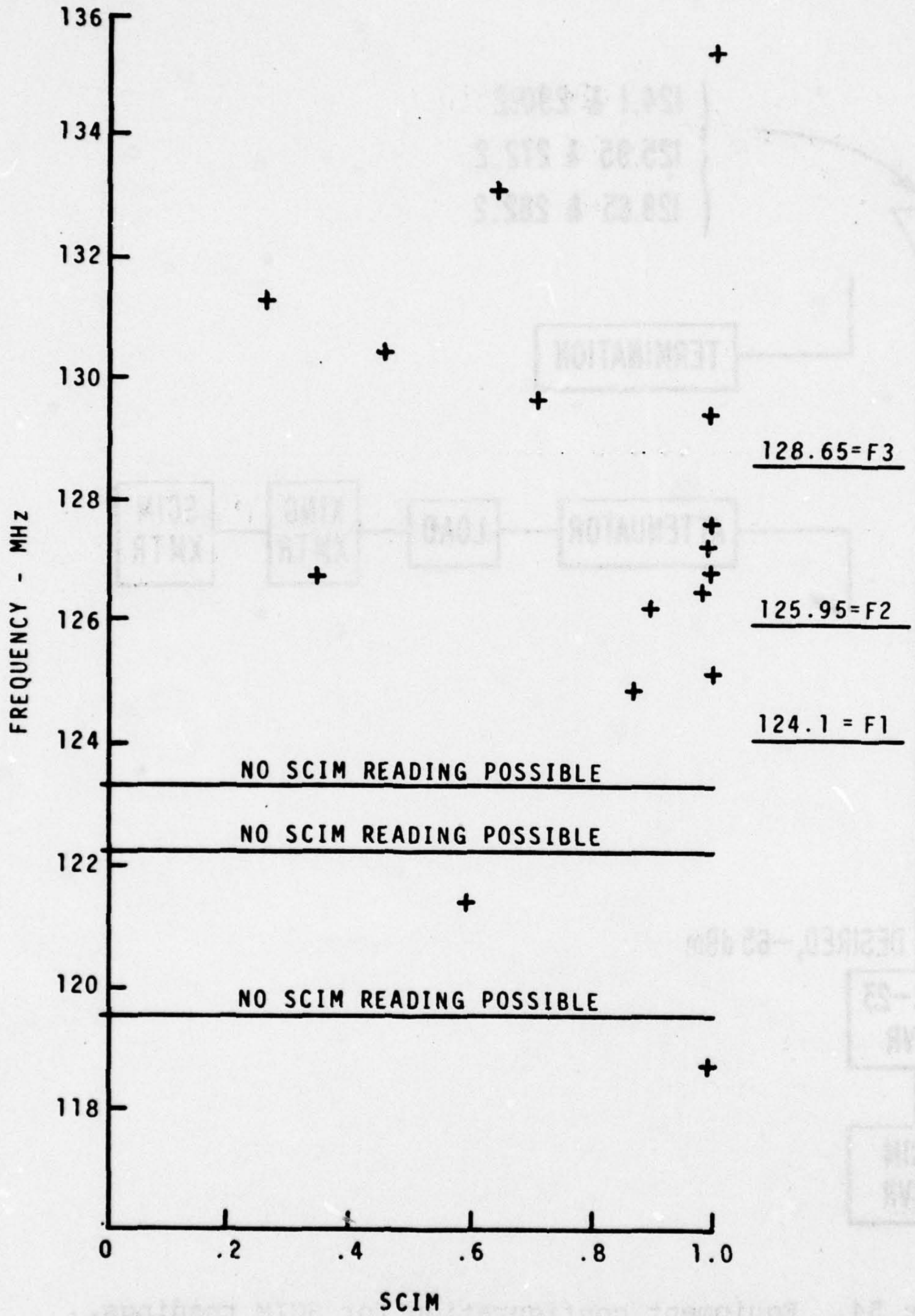

Figure 55. SCIM readings at generated IM frequencies when all 3 VHF and 3 UHF transmitters are keyed.

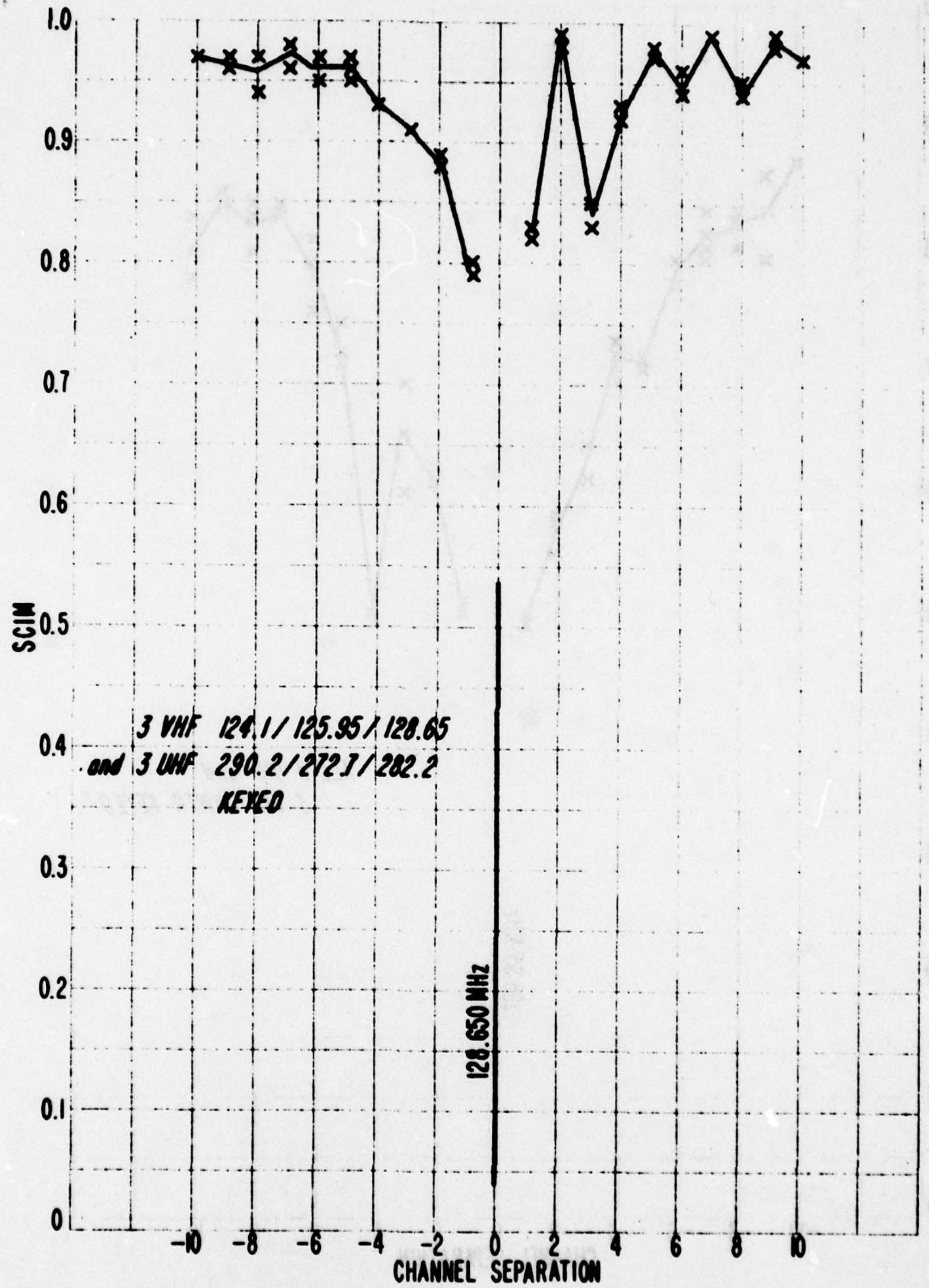

Figure 56. SCIM readings for on site co-channel measurements (center frequency 125.95 MHz). (GRR-23 receiver)

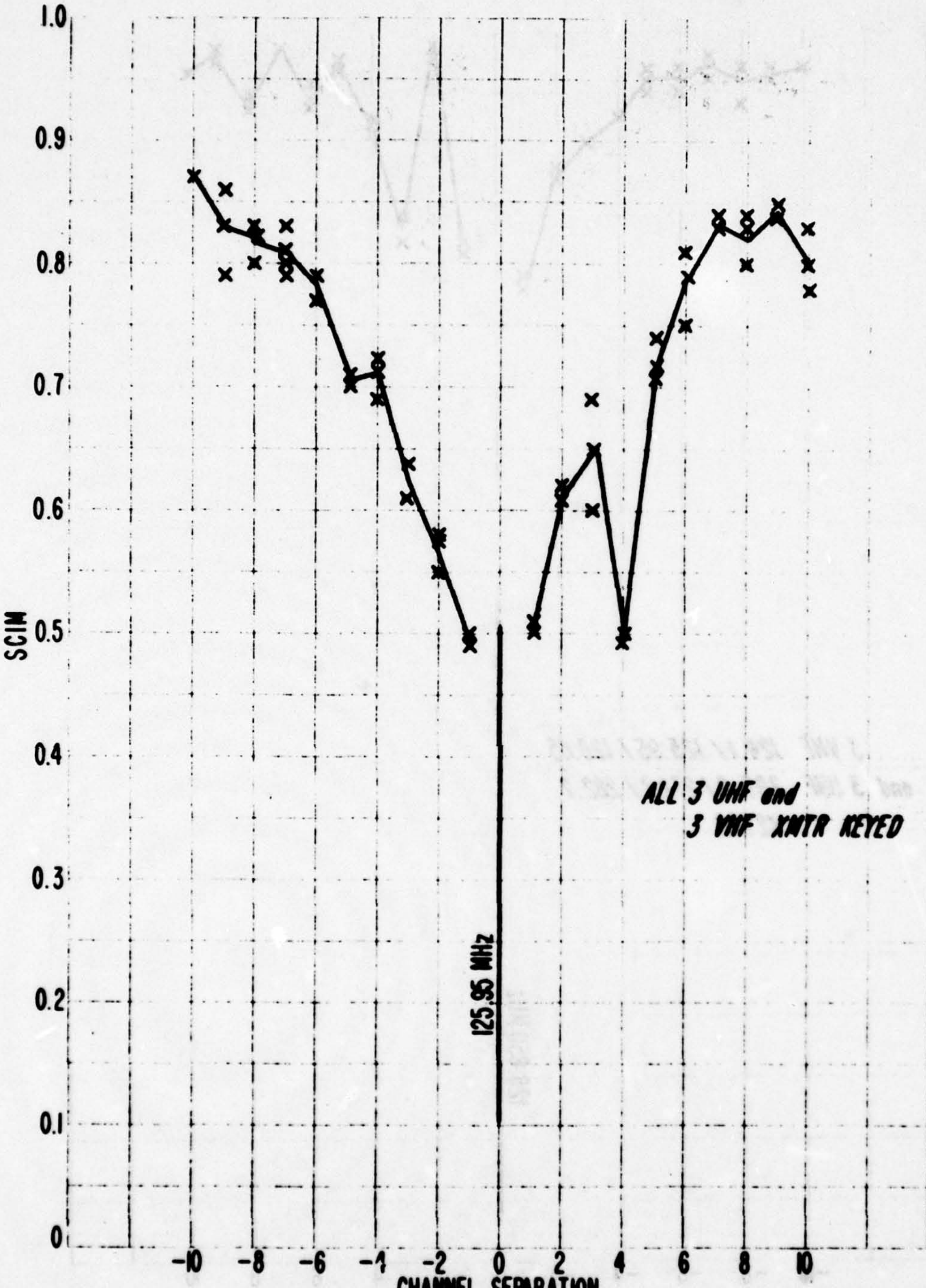

Figure 57. SCIM readings for on site co-channel measurements (center frequency 125.95 MHz). (GRR-23 receiver)

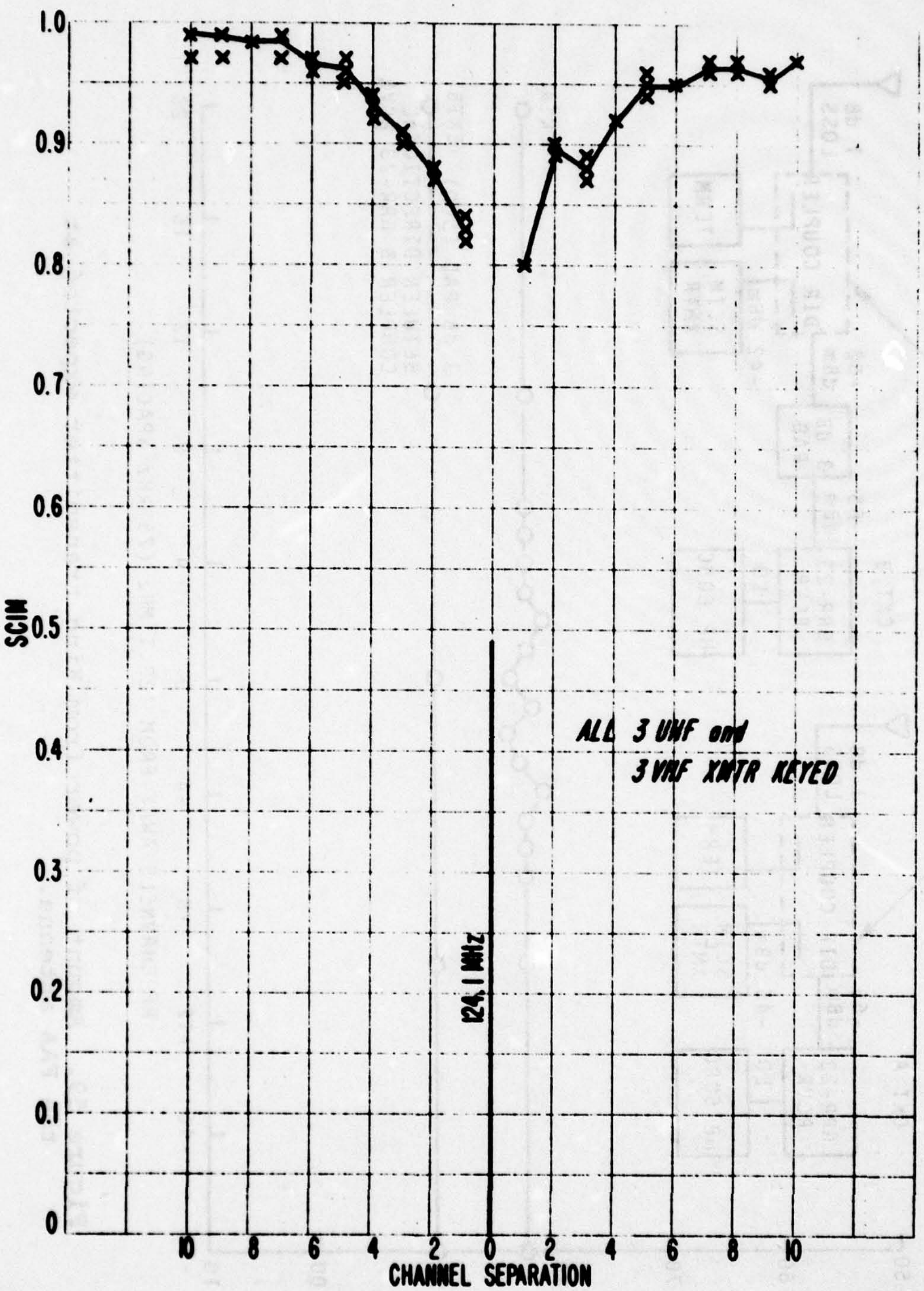

Figure 58. SCIM readings for on-site co-channel measurements (center frequency 124.1 MHz). (GRR-23 receiver)

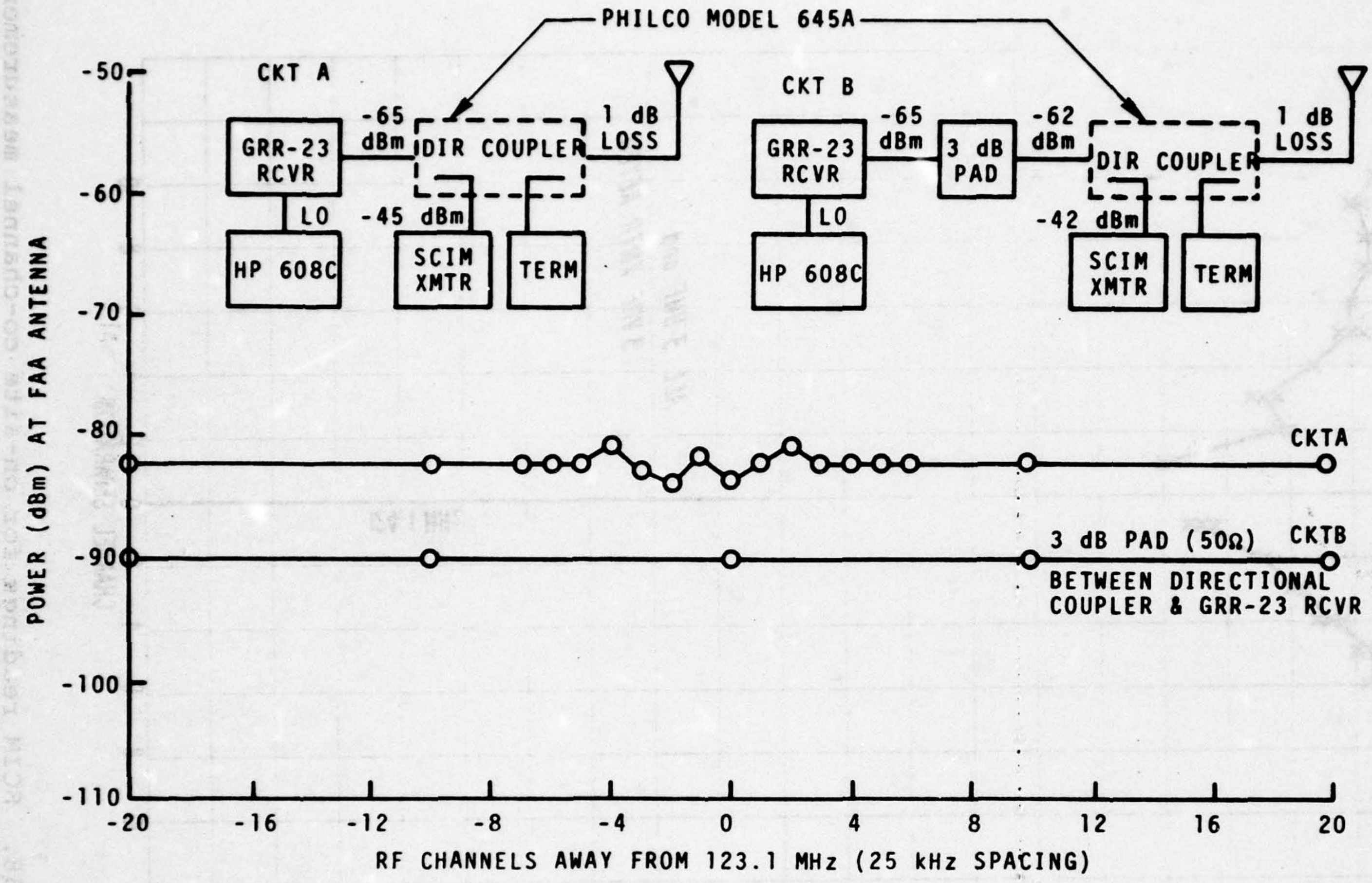

Figure 59. Amount of power from King transmitter expected at the FAA antenna.

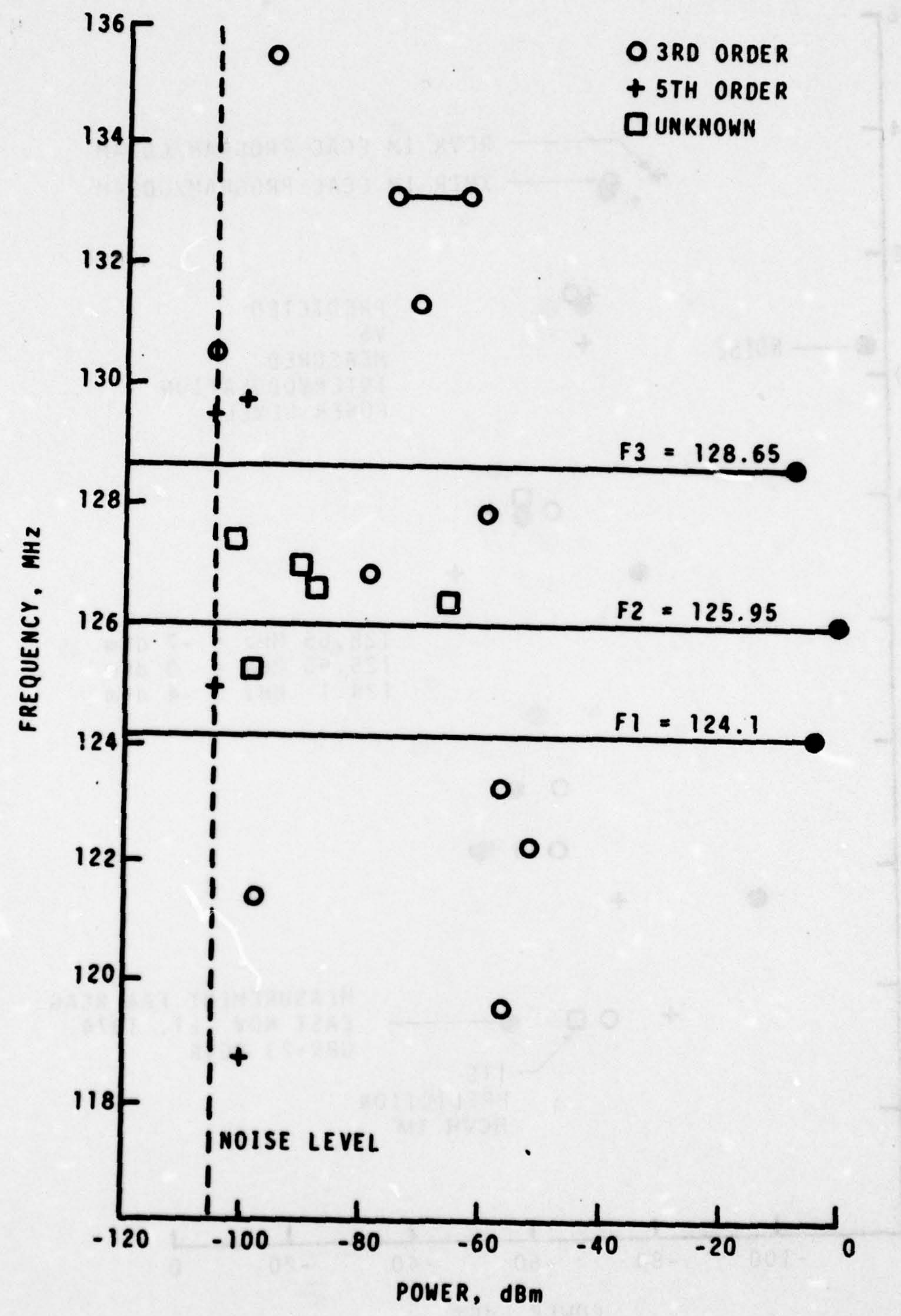

Figure 60. Reception of desired and undesired rf signals at FAA's RCAG East Site at Aurora, Colorado.

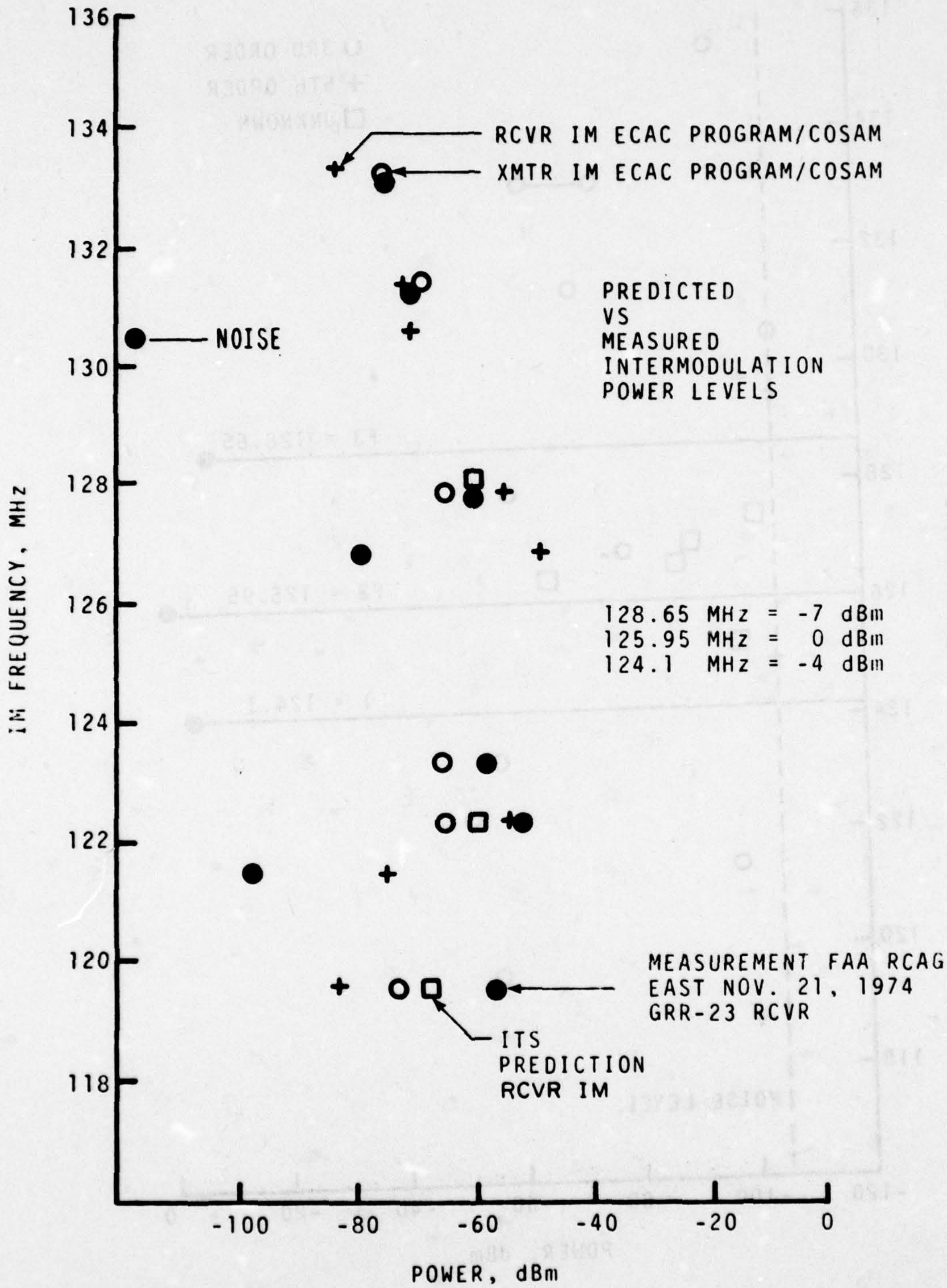

Figure 61. Comparison of COSAM predicted intermodulation levels with on-site measurements.

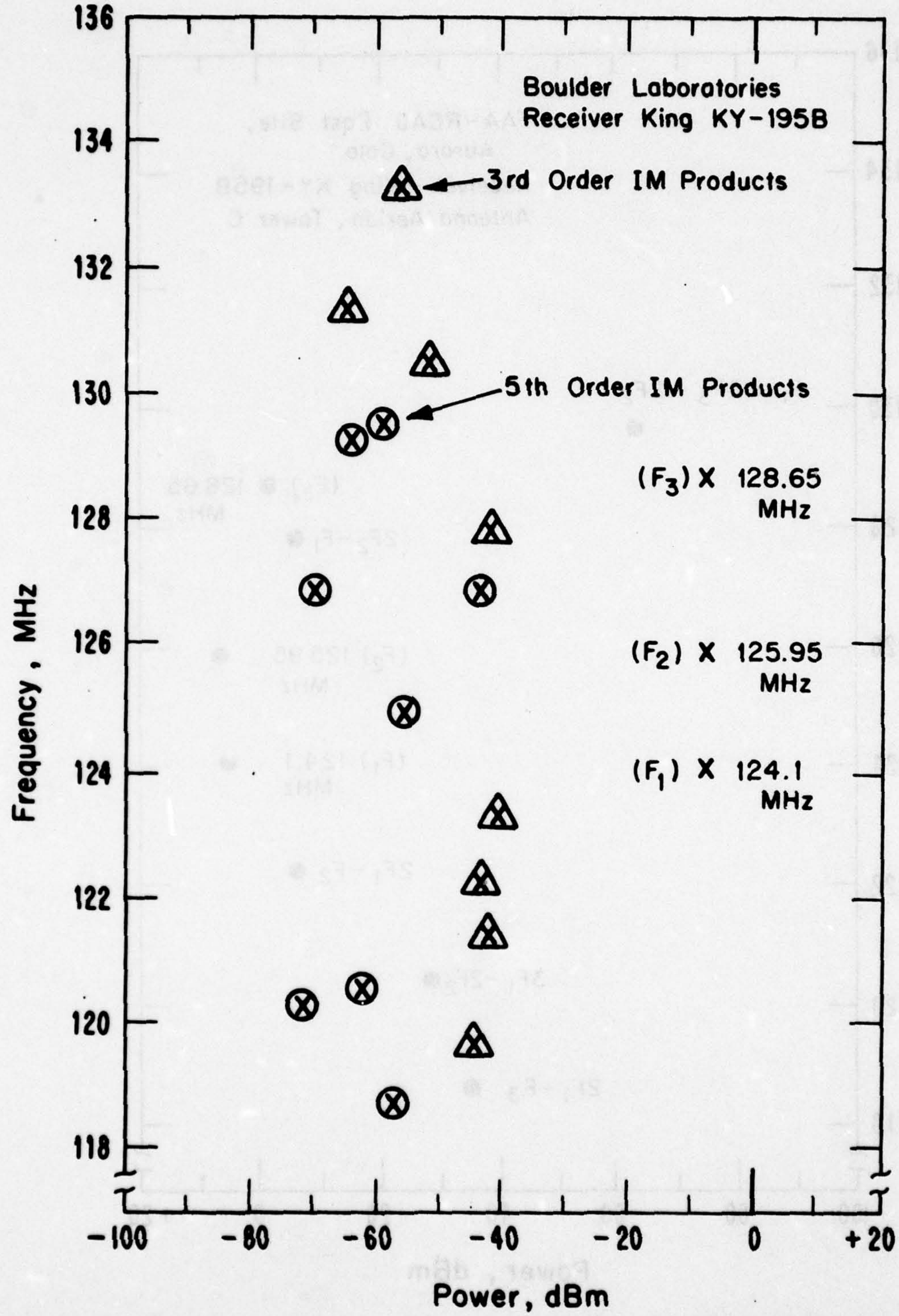

Figure 62. Laboratory measurements of intermodulation products when the three primary frequencies are keyed at 0 dBm, into the King receiver.

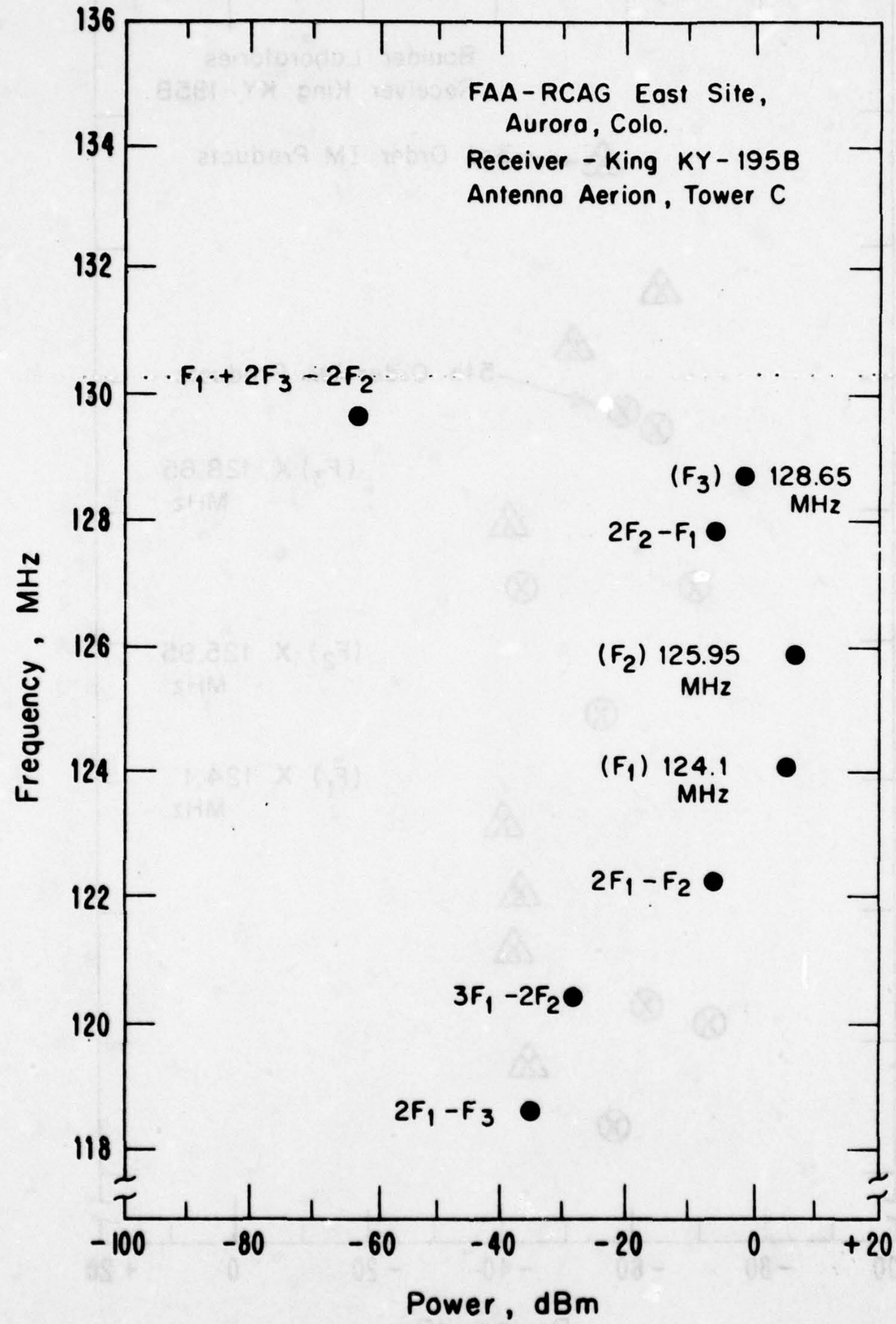

Figure 63. Site measurements of intermodulation products with the primary frequency levels as shown into the King receiver.

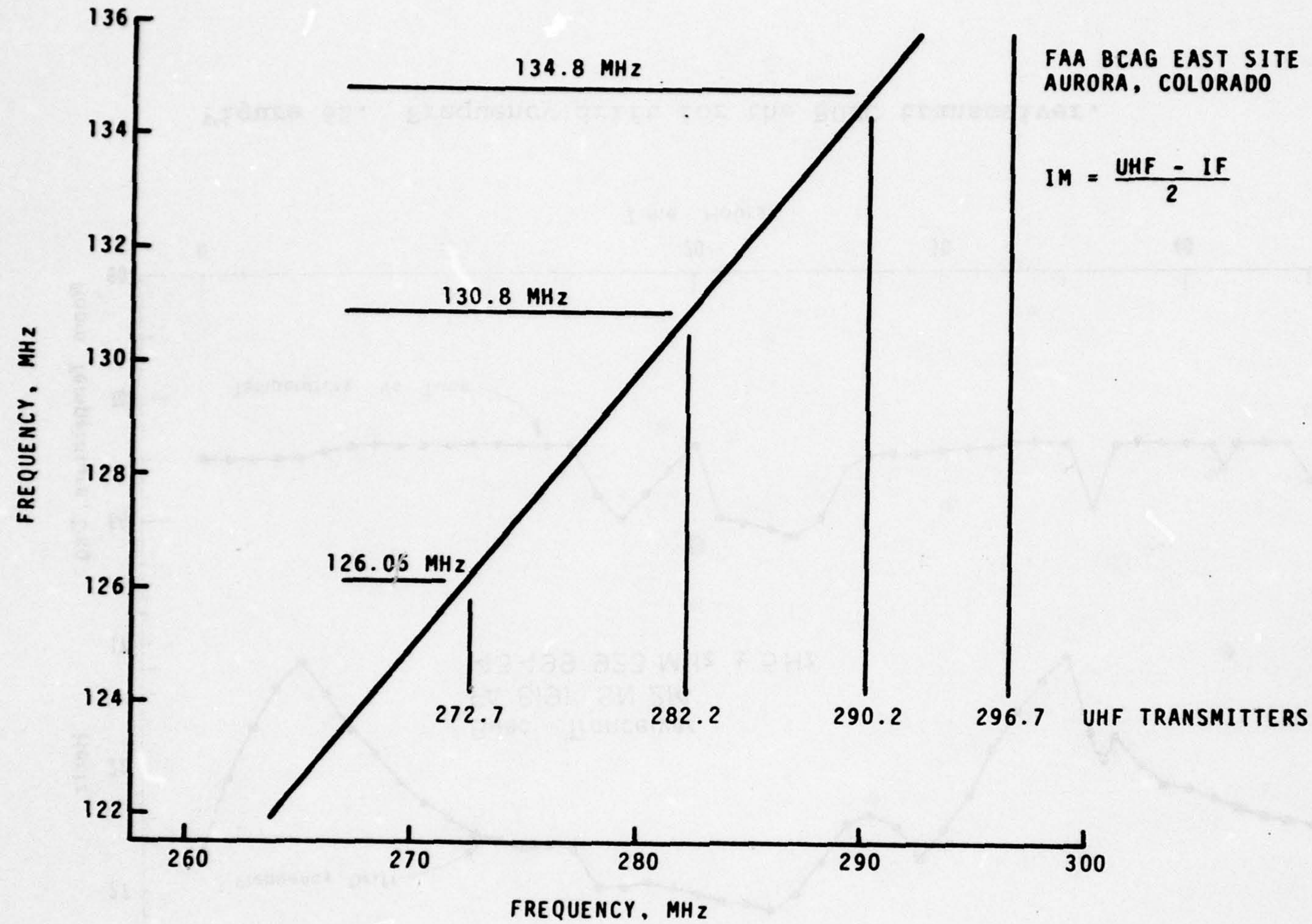

Figure 64. Interference possible by the radiation from the UHF transmitters at the FAA RCAG East site in Aurora, Colo.

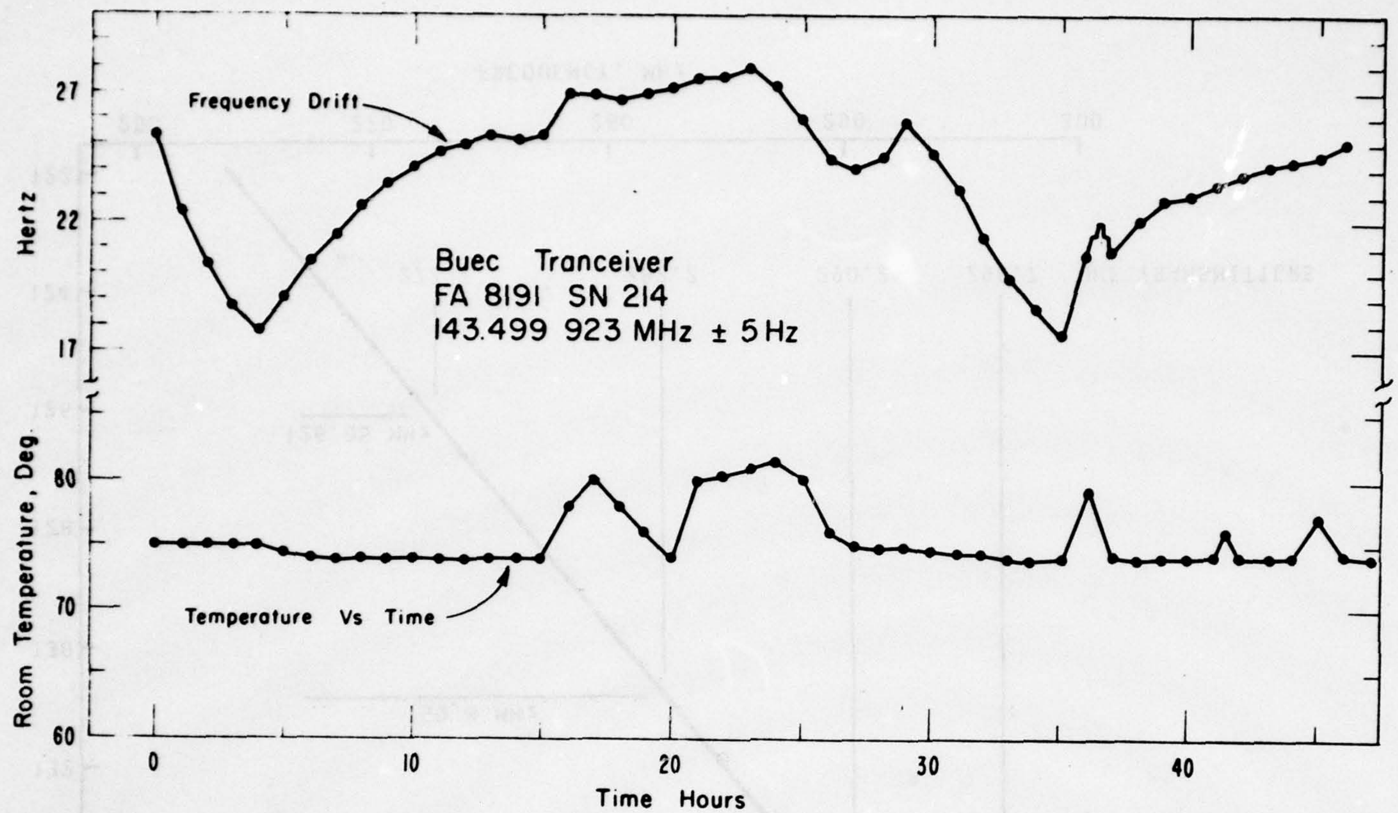

Figure 65. Frequency drift for the BUEC transceiver.

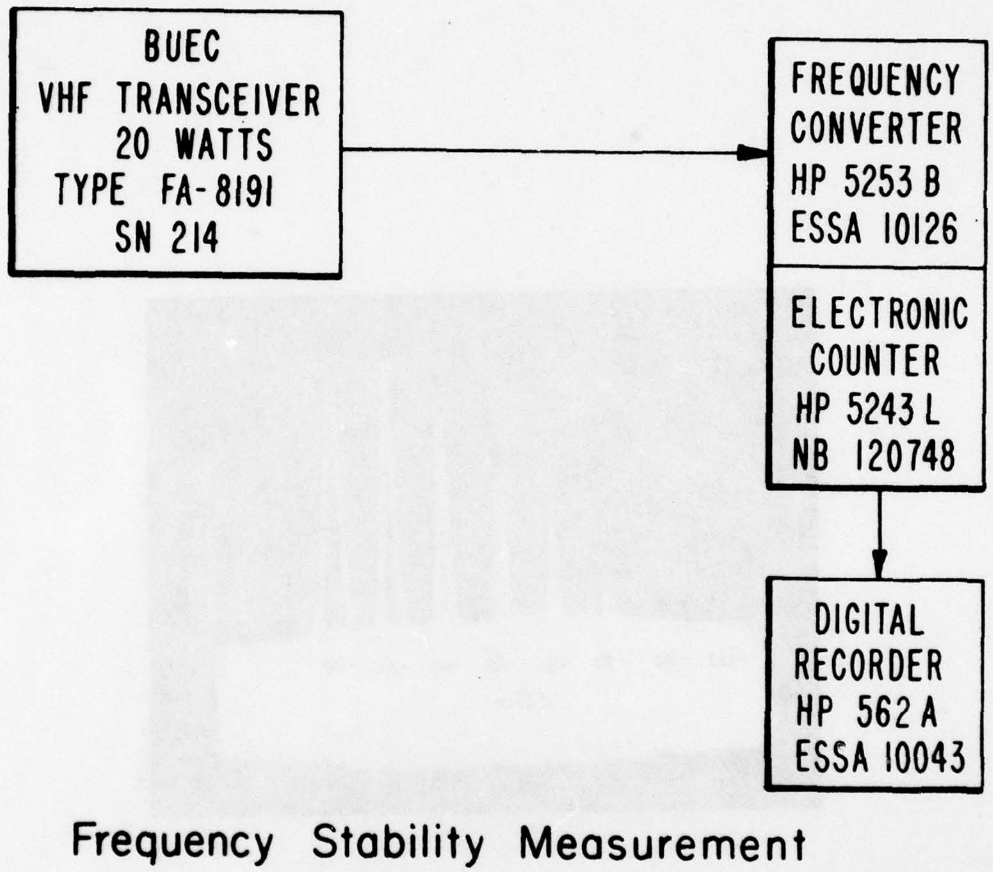

Figure 66. Equipment configuration for frequency drift measurements of the BUEC VHF transceiver.

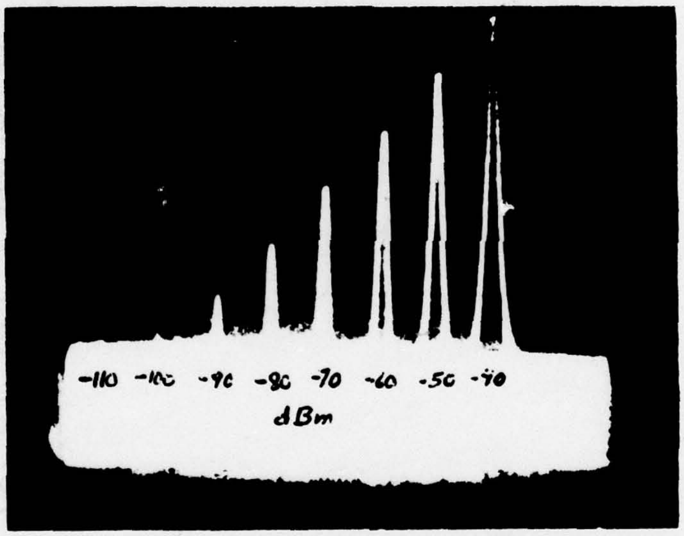

Figure 67. Calibration of the HP Spectrum Analyzer.

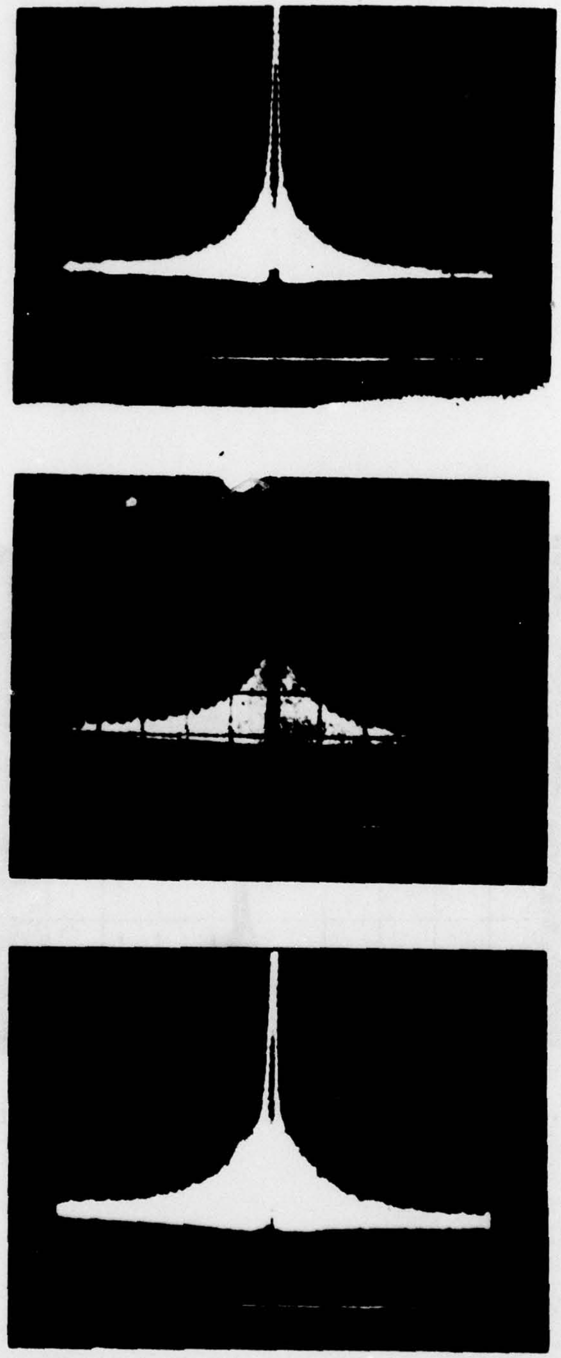

Figure 68. Spectral display of three rf sources: (top) HP 608C signal generator; (center) King KY-195B transmitter; (bottom) GRT-21 transmitter.

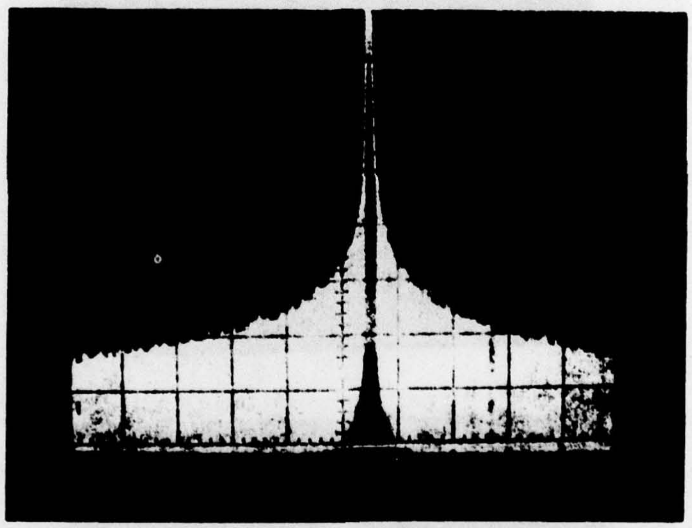

Figure 69. Spectral display of TV-6 transmitter.

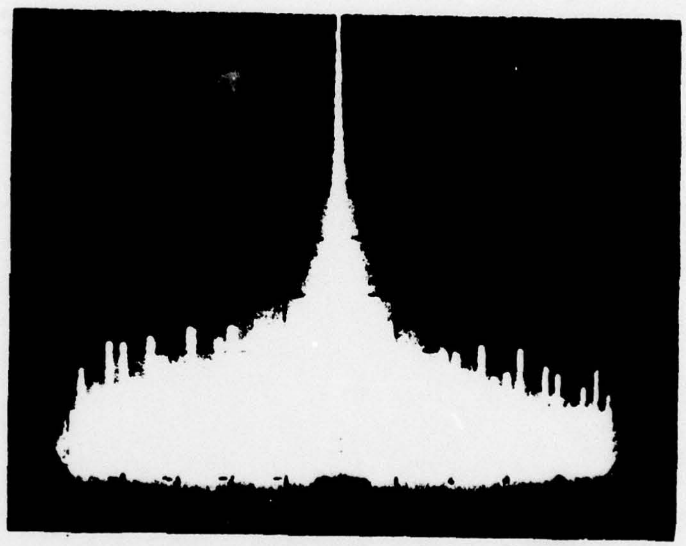

Figure 70. King KY-195B transmitter calibration. Retuned notch filter.

APPENDIX A. COMPUTER PROGRAM

The listed program computes the location of possible intermodulation products through fifth order in the band 118 to 136 MHz. The program is restricted to intermodulation products produced by three frequencies or less. The program accepts as input three VHF frequencies in the band 118 to 136 MHz and three UHF frequencies in the band 225 to 400 MHz. If less than three VHF frequencies are used, one of those used must be repeated to bring the total number of VHF input frequencies to three. The case is similar for the UHF input frequencies. If no VHF frequencies are specified, zero should be entered for all three, and if no UHF frequencies are specified, 225 should be entered for all three.

APPENDIX A: COMPUTER PROGRAM LISTING

```
      PROGRAM FRINTFR (INPUT, OUTPUT, PUNCH, TAPE60=INPUT, TAPE61=OUTPUT**
     1, TAPE62=PUNCH)
C         PROGRAM TO COMPUTE THE INETEFERENCE FREQUENCIES AND MAKE A
C        TABULATION OF THE 2ND, 3RD, 4TH AND THE 5TH ORDER OCCURENCES
      DIMENSION FINT (19, 32), IFINT (19, 32), TABV (20), IDENT (4)
      DIMENSION TABH (45), F (6), AINT (12), IFINTN (19, 64)
       DIMENSION ISYMBL (20, 40)
C
C
      COMMON /1 /AFINT, II, JJ, TABV, TABH, FINT, IFINTN, NC, NORDER, NI
     1NT, IFINT, IA, ISYMBL
C
      INTEGER FINT
C
C
      DATA (IBLANK = 10H          )
      DATA  IBLANK / 10H          /, IRB/1R /
  100 READ 1500, F1, F2, F3, F4, F5, F6, IDENT
C
      IF (EOF( 60))105, 110                                          **
  105 CALL EXIT
  110 CONTINUE
      NORDER = 2
C
  115 DO 125 I = 1, 19
      DO 120 J = 1, 40
      IFINTN (I, J) = IBLANK
      IFINTN (I, J + 40) = IBLANK
      FINT (I, J) = IBLANK
      IFINT (I, J) = IBLANK
  120 CONTINUE
  125 CONTINUE
C
      F (1) = F1
      F (2) = F2
      F (3) = F3
      F (4) = F4
      F (5) = F5
      F (6) = F6
C
      FBASE = 118.0
      DO 130 I = 1, 20
      TABV (I) = FBASE + FLOAT (I - 1)
  130 CONTINUE
      FINC = 0.025
      DO 135 J = 1, 41
      TABH (J) = 0.0 + FLOAT (J - 1) * FINC
  135 CONTINUE
C
C
C
      INTFN = NORDER - 1
      GO TO (140, 190, 235, 245), INTFN
C
C              2 ND ORDER INTERFERENCE COMPUTATION
C
C
  140  DO 141 J = 1, 800
       ISYMBL (J) = IRB
  141  CONTINUE
      NC = 0
      PRINT 1502, 2
      NINT = 0
```

```
C
      DO 160 I = 1, 3
      NB = 4
 145  DO 150 J = NB, 6
      JB = J
      NINT = NINT + 1
      AFINT = F (J) - F (I)
      PRINT 1504, I, J, AFINT
      IF (AFINT .LT. 137.0 .AND. AFINT .GE. 118.0) PRINT 1506, NC, AFINT
     1, F (J), J, F (I), I
      IF (AFINT .LT. 137.0 .AND. AFINT .GE. 118.0) GO TO 155
 150  CONTINUE
      GO TO 160
C
C
 155  CALL TABULAT
C
      IF (JB .LT. 6)NB = JB + 1
      IF (JB .LT. 6) GO TO 145
 160  CONTINUE
C
      DO 185 K = 1, 3
      NINT = NINT + 1
      IF (K - 2)165, 170, 175
 165  AFINT = F5 - F4
      PRINT 1506, NINT, AFINT, F5, 5, F4, 4
      GO TO 180
 170  AFINT = F6 - F4
      PRINT 1506, NINT, AFINT, F6, 6, F4, 4
      GO TO 180
 175  AFINT = F6 - F5
      PRINT 1506, NINT, AFINT, F6, 6, F5, 5
 180  IF (AFINT .LT. 118.0 .OR. AFINT .GE. 137.0) GO TO 185
C
      CALL TABULAT
C
 185  CONTINUE
C
      GO TO 275
C
C
C                3RD ORDER INTERFERENCE
C
 190   DO 191 J = 1, 800
       ISYMBL (J) = IRB
 191   CONTINUE
      NC = 0
      PRINT 1502, 3
      AFINT = 2 * F1 - F2
      NINT = 1
      CALL TABULAT
      AFINT = 2 * F1 - F3
      NINT = 3
      CALL TABULAT
      AFINT = 2 * F2 - F1
      NINT = 5
      CALL TABULAT
      AFINT = 2 * F2 - F3
      NINT = 7
      CALL TABULAT
      AFINT = 2 * F3 - F1
      NINT = 9
      CALL TABULAT
      AFINT = 2 * F3 - F2
```

```
      NINT = 11
      CALL TABULAT
C
      DO 205 K = 4, 6
      DO 195 L = 1, 3
      NINT = NINT + 2
      AFINT = F (K) - 2 * F (L)
      CALL TABULAT
  195 CONTINUE
  205 CONTINUE
C
      AFINT = 2 * F4 - F5
      NINT = 31
      CALL TABULAT
      AFINT = 2 * F4 - F6
      NINT = 33
      CALL TABULAT
      AFINT = 2 * F5 - F4
      NINT = 35
      CALL TABULAT
      AFINT = 2 * F5 - F6
      NINT = 37
      CALL TABULAT
      AFINT = 2 * F6 - F4
      NINT = 39
      CALL TABULAT
      AFINT = 2 * F6 - F5
      NINT = 41
      CALL TABULAT
C
      AFINT = F1 + F2 - F3
      NINT = 43
      CALL TABULAT
      AFINT = F1 + F3 - F2
      NINT = 43
      CALL TABULAT
      AFINT = F2 + F3 - F1
      NINT = 43
      CALL TABULAT
C
      DO 215 K = 4, 6
      AFINT = F (K) - F1 - F2
      NINT = NINT + 2
      CALL TABULAT
      AFINT = F (K) - F2 - F3
      NINT = NINT + 2
      CALL TABULAT
      AFINT = F (K) - F1 - F3
      NINT = NINT + 2
      CALL TABULAT
  215 CONTINUE
C
      DO 225 I = 1, 3
      AFINT = F (I) + F4 - F5
      NINT = NINT + 2
      CALL TABULAT
      AFINT = F (I) + F4 - F6
      NINT = NINT + 2
      CALL TABULAT
      AFINT = F (I) + F5 - F4
      NINT = NINT + 2
      CALL TABULAT
      AFINT = F (I) + F5 - F6
      NINT = NINT + 2
```

```
      CALL TABULAT
      AFINT = F (I) + F6 - F4
      NINT = NINT + 2
      CALL TABULAT
      AFINT = F (I) + F6 - F5
      NINT = NINT + 2
      CALL TABULAT
  225 CONTINUE
C
      AFINT = F4 + F5 - F6
      NINT = 99
      CALL TABULAT
      AFINT = F5 + F6 - F4
      NINT = 99
      CALL TABULAT
      AFINT = F6 + F4 - F5
      NINT = 99
      CALL TABULAT
C
      GO TO 275
C
C
C
C               4TH ORDER INTERFERENCE
C
  235  DO 236 J = 1, 800
       ISYMBL (J) = IRB
  236  CONTINUE
      NC = 0
      PRINT 1502, 4
      AFINT = 2.0 * (F4 - F5)
      NINT = 1
      CALL TABULAT
      AFINT = 2.0 * (F4 - F6)
      NINT = 3
      CALL TABULAT
      AFINT = 2.0 * (F5 - F6)
      NINT = 5
      CALL TABULAT
      AFINT = 2.0 * (F5 - F4)
      NINT = 7
      CALL TABULAT
      AFINT = 2.0 * (F6 - F5)
      NINT = 9
      CALL TABULAT
      AFINT = 2.0 * (F6 - F4)
      NINT = 11
      CALL TABULAT
C
C
      GO TO 275
C
C
C               5TH ORDER INTERFERENCE
C
  245  DO 246 J = 1, 800
       ISYMBL (J) = IRB
  246  CONTINUE
      NC = 0
      PRINT 1502, 5
C
      AFINT = 3.0 * F1 - 2.0 * F2
      NINT = 1
      CALL TABULAT
```

```
      AFINT = 3.0 * F1 - 2.0 * F3
      NINT = 3
      CALL TABULAT
      AFINT = 3.0 * F2 - 2.0 * F1
      NINT = 5
      CALL TABULAT
      AFINT = 3.0 * F2 - 2.0 * F3
      NINT = 7
      CALL TABULAT
      AFINT = 3.0 * F3 - 2.0 * F1
      NINT = 9
      CALL TABULAT
      AFINT = 3.0 * F3 - 2.0 * F2
      NINT = 11
      CALL TABULAT
C
      DO 265 J = 4, 6
      DO 255 I = 1, 3
      AFINT = 2.0 * F (J) - 3.0 * F (I)
      NINT = NINT + 2
      CALL TABULAT
  255 CONTINUE
  265 CONTINUE
C
C
      AFINT = 3.0 * F4 - 2.0 * F5
      NINT = 31
      CALL TABULAT
      AFINT = 3.0 * F4 - 2.0 * F6
      NINT = 33
      CALL TABULAT
      AFINT = 3.0 * F5 - 2.0 * F4
      NINT = 35
      CALL TABULAT
      AFINT = 3.0 * F5 - 2.0 * F6
      NINT = 37
      CALL TABULAT
      AFINT = 3.0 * F6 - 2.0 * F4
      NINT = 39
      CALL TABULAT
      AFINT = 3.0 * F6 - 2.0 * F5
      NINT = 41
      CALL TABULAT
C
C
      AFINT = F1 + 2 * (F2 - F3)
      NINT = 43
      CALL TABULAT
      AFINT = F2 + 2 * (F1 - F3)
      NINT = 45
      CALL TABULAT
      AFINT = F3 + 2 * (F1 - F2)
      NINT = 47
      CALL TABULAT
      AFINT = F1 + 2 * (F3 - F2)
      NINT = 49
      CALL TABULAT
      AFINT = F2 + 2 * (F3 - F1)
      NINT = 51
      CALL TABULAT
      AFINT = F3 + 2 * (F2 - F1)
      NINT = 53
      CALL TABULAT
C
```

```
C
C                PRINTOUT OF THE COMPUTED LOCATIONS OF INTERFERENCE
C
  275   CONTINUE
        IF (NC .EQ. 0) PRINT 1509, NORDER
        IF (NC .EQ. 0) GO TO 295
C
C
C             PRINT OUT OF THE CONDENSED INTERFERENCE LISTING
C                  S = SECOND ORDER             T = THIRD ORDER
C                  F = FOURTH ORDER    .        V = FIFTH ORDER
C
        PRINT 1510, IDENT, F1, F2, F3, F4, F5, F6
C
        IF (NORDER .EQ. 2) PRINT 1512
        IF (NORDER .EQ. 3) PRINT 1514
        IF (NORDER .EQ. 4) PRINT 1516
        IF (NORDER .EQ. 5) PRINT 1518
        PRINT 1520, NC
C
         PRINT 600
         PRINT 610
C
         DO 280 J = 1, 20
         PRINT 620, TABV(J), (ISYMBL(J, K), K = 1, 40), TABV(J)
  280    CONTINUE
C
  600    FORMAT (7X, *.0*, 6X, *.1*, 6X, *.2*, 6X, *.3*, 6X, *.4*, 6X,
       1 *.5*, 6X, *.6*, 6X, *.7*, 6X, *.8*, 6X, *.9*)
  610    FORMAT (8X, *. . . . . . . . . . . . . . . . . . . . . . . . .
       *. . . . . . . . . . . . . . .*)
  620    FORMAT (1X, F3.0, *.-*, 40(1X, R1), * -*, F3.0, *.*)
C
         PRINT 610
         PRINT 600
C
        PRINT 1510, IDENT, F1, F2, F3, F4, F5, F6
C
C
        IF (NORDER .EQ. 2) PRINT 1512
        IF (NORDER .EQ. 3) PRINT 1514
        IF (NORDER .EQ. 4) PRINT 1516
        IF (NORDER .EQ. 5) PRINT 1518
        PRINT 1520, NC
C
        PRINT 1530
        PRINT 1532
        PRINT 1534
        PRINT 1536
C
        IF (NORDER .GT. 2) GO TO 305
C
  295   NORDER = NORDER + 1
        IF (NORDER .LE. 5) GO TO 115
        GO TO 100
C
  305    CONTINUE
C
        NORDER = NORDER + 1
        IF (NORDER .LE. 5) GO TO 115
        GO TO 100
C
C
C
```

```
C
C
C
 1500  FORMAT   (6F6.3, 4X, 4A10)
 1502  FORMAT   (*1INTERFERENCE*, I3, *   ORDER COMPUTATION*)
 1504  FORMAT   (*0INDEX I =*, I4, *  INDEX J = *, I4, *  AFINT =*, F8.3)
      1
 1506   FORMAT (I3, *  INTERFERENCE FREQUENCY OF*, F10.3, 5X, 2(F8.3, 1X,
      * *F*, I1, 5X))
 1508  FORMAT (       *  THERE WERE NO INTERFERENCE FOR ORDER NO.*, I3)
       DATA  IRS  /1RS/,  IRT  /1RT/,  IRF  /1RF/,  IRV  /1RV/
 1510  FORMAT   (1H1, 30X,4A10, / / , * THE THREE VHF FREQUENCIES ARE*, 3F
      110.3, / , * THE THREE UHF FREQUENCIES ARE*, 3F10.3, / / )
 1512  FORMAT   (30X, * COMPUTING THE 2ND ORDER INTERFERENCE.*)
 1514  FORMAT   (30X, * COMPUTING THE 3RD ORDER INTERFERENCE.*)
 1516  FORMAT   (30X, * COMPUTING THE 4TH ORDER INTERFERENCE.*)
 1518  FORMAT   (30X, * COMPUTING THE 5TH ORDER INTERFERENCE.*)
 1520  FORMAT   (35X, *THERE WERE*, I4, *  COMBINATIONS*, / / )
 1522  FORMAT   (*0*, F3.0, *. *, A10, 9(3X, A10), 3X, *-*)
 1524  FORMAT   (2X, 10(3X, A10), 3X, *-*)
 1526  FORMAT   (2X, 10(3X, A10))
 1528  FORMAT   (5X, 10(3X, A10))
 1530  FORMAT   (* LINE 1 .000*, 9X, *.025*, 9X, *.050*, 9X, *.075*, 9X, *
      1.100*, 9X, *.125*, 9X, *.150*, 9X, *.175*, 9X, *.200*, 9X, *.225*)
      2
 1532  FORMAT   (* LINE 2 .250*, 9X, *.275*, 9X, *.300*, 9X, *.325*, 9X, *
      1.350*, 9X, *.375*, 9X, *.400*, 9X, *.425*, 9X, *.450*, 9X, *.475*)
      2
 1534  FORMAT   (* LINE 3 .500*, 9X, *.525*, 9X, *.550*, 9X, *.575*, 9X, *
      1.600*, 9X, *.625*, 9X, *.650*, 9X, *.675*, 9X, *.700*, 9X, *.725*)
      2
 1536  FORMAT   (* LINE 4 .750*, 9X, *.775*, 9X, *.800*, 9X, *.825*, 9X, *
      1.850*, 9X, *.875*, 9X, *.900*, 9X, *.925*, 9X, *.950*, 9X, *.975*)
      2
       END
       SUBROUTINE TABULAT
C
       DIMENSION FINT (19, 32), IFINT (19, 32), AINT (12), TABV (20)
       DIMENSION TABH (45), F (6), IFINTN (19, 64)
       DIMENSION INTF3 (100), INTF4 (12), INTF5  (54)
       DIMENSION INTF3R (50), INTF4R (6), INTF5R (27)
        DIMENSION ISYMBL (20, 40)
C
C
       INTEGER FINT
C
C
C
C
C
C
C
       COMMON /1 /AFINT, II, JJ, TABV, TABH, FINT, IFINTN, NC, NORDER, NI
      1NT, IFINT, IA, ISYMBL
C
       IF (AFINT .GT. 136.0 .OR. AFINT .LT. 118.0) RETURN
       NC = NC + 1
C
       DO 100 K = 1, 19
       II = K
       TSTV = TABV (II)
       TSTC = TABV (II + 1)
       IF (AFINT .LT. TSTC) GO TO 105
  100  CONTINUE
```

```
 105  CONTINUE
C
      ITST = AFINT
      FTST = AFINT - FLOAT (ITST)
      JJ = FTST / .025 + 1.001
C
      PRINT 1512, NINT, II, JJ
C
C        SET UP OF THE SYMBOLS FOR THE CONDENSED  PRINT OUT
C
       IF (NORDER .EQ. 2) ISYMBL (II, JJ) = IRS
       IF (NORDER .EQ. 3) ISYMBL (II, JJ) = IRT
       IF (NORDER .EQ. 4) ISYMBL (II, JJ) = IRF
       IF (NORDER .EQ. 5) ISYMBL (II, JJ) = IRV
C
      IF (NORDER .NE. 2) GO TO 110
      IFINT (II, JJ) = AINT (NINT)
      GO TO 130
C
 110  NITTM = NINT
      NITT = NINT + 1
      JJT = JJ * 2
      JJTM = JJT - 1
      IF (NORDER - 4)115, 120, 125
C
 115  IFINTN (II, JJTM) = INTF3 (NITTM)
      IFINTN (II, JJT) = INTF3 (NITT)
      GO TO 130
C
 120  IFINTN (II, JJTM) = INTF4 (NITTM)
      IFINTN (II, JJT) = INTF4 (NITT)
      GO TO 130
C
 125  IFINTN (II, JJTM) = INTF5 (NITTM)
      IFINTN (II, JJT) = INTF5 (NITT)
C
C
 130  ENCODE (8, 1514, IAF)AFINT
C
      FINT (II, JJ) = IAF
      IF (NORDER .EQ. 2) PRINT 1516, FINT (II, JJ), IFINT (II, JJ), II,
     1JJ, NINT, AFINT
      IF (NORDER .GT. 2) PRINT 1518, FINT (II, JJ), IFINTN (II, JJTM), I
     1FINTN (II, JJT), II, JJTM, JJT, NINT, AFINT
      RETURN
C
C
1500  FORMAT  (*0INTF *)
1502  FORMAT  (1H0, 10(    A10), / / )
1504  FORMAT  (*0INTF3*)
1506  FORMAT  (1H0, 10(R3, A10), / / )
1508  FORMAT  (*0INTF4*)
1510  FORMAT  (*0INTF5*)
1512  FORMAT  (*0*, 3I4, *  FROM TABULAT*)
1514  FORMAT  (F8.3)
1516  FORMAT  (* FINT(II,JJ) = *,A10, *  IFINT(II,JJ) =*,A10, *  II =*,
     1I4, *  JJ =*, I4, *  NINT =*, I4, *  AFINT =*, F10.3)
1518  FORMAT  (* FINT(II,JJ) = *,A10, *  IFINTN(II,JJ+) =*, R3,A10, *  I
     1I =*, I4, *  JJTM,JJT =*, 2I3, *  NINT*, I3, *  AFINT =*, F10.3)
     2
      END
```